2017 INFORMS PRIZE

The Nomination of The United States Air Force

U.S. AIR FORCE OPERATIONS RESEARCH

Nomination of the United States Air Force for the 2017 INFORMS Prize

Required Material

- **Nomination Endorsement from the Secretary of the U.S. Air Force** 4
- **Summary of the U.S. Air Force Nomination for the 2017 INFORMS Prize** 5
- **Exemplar Operations Research Topics in the U.S. Air Force** 8
  - Warner Robins Aircraft Repair and Overhaul 8
  - Post–Cold War Nuclear Deterrence Analysis 9
  - Transforming Defense Testing Using Design of Experiments 10
- **Endorsements** 11

  U.S. AIR FORCE LEADERS
  - Honorable Donald Rice, former Secretary of the Air Force 12
  - Mark A. Welsh III, General (retired), Chief of Staff of the Air Force, 2012–2016 14
  - Larry D. Welch, General (retired), Chief of Staff of the Air Force, 1986–1990 15

  CONGRESS AND (U.S. AND ALLIED) DEFENSE LEADERS
  - Honorable Ted Lieu, House Committee on Oversight and Government Reform, Subcommittee on National Security 16
  - Honorable Dr. Harold Brown, former Secretary of Defense 17
  - Honorable Eric K. Fanning, Secretary of the Army 18
  - Honorable Dr. Jamie Morin, Director, Cost Assessment and Program Evaluation, Office of the Secretary of Defense 19
  - Mr. Alan R. Shaffer, Director of NATO's Science and Technology Collaboration Office 20
  - Dr. Todd Mansell, Chief of the Joint and Operations Analysis Division, Australian Defence Department's Strategic Policy and Intelligence Group 21

  ACADEMIA AND PROFESSIONAL SOCIETIES
  - Dr. Cynthia Barnhart, MIT, past INFORMS President 22
  - Mr. Thomas Denesia, President of the Military Operations Research Society, and Mr. Chris Arney, President of the Military Applications Society 23

  INDUSTRY
  - Dr. David S. Chu, President of the Institute for Defense Analyses 25
  - Dr. Les Servi, MITRE, INFORMS Fellow 26
  - Dr. Fred Glover, Chief Technology Officer, OptTek Systems, Inc., INFORMS Fellow 27
- **U.S. Air Force Operations Research Education and Publications** 28
- **U.S. Air Force Operations Research Awards** 31
- **U.S. Air Force INFORMS Prize Committees** 33

Supplemental Material (Appendixes)

The following is a list of supplemental material presented in a separate document. It is included here for reference; please see the Supplemental Material document for the full content.

- **APPENDIX 1. U.S Air Force Contributions to the Foundations of Operations Research**
  - Linear Programming in Project SCOOP (Scientific Computation of Optimal Programs)
  - Network Modeling
  - Dynamic Programming
  - Game Theory
  - Simulation and Statistics
  - Cost Analysis
  - Production and Inventory Control
  - References
- **APPENDIX 2. Additional Exemplar Operations Research Topics in the U.S. Air Force**
  - Logistics and Infrastructure
  - Manpower Analysis
  - Operational Effectiveness
  - Acquisition of New Systems
  - Cost Analysis
- **APPENDIX 3. 75 Years of Operations Research in the U.S. Air Force (1942–2017)**
  - World War II and the Origins of Operations Research, 1940s
  - Institutionalizing O.R. Talent, 1950s
  - Force Structure Analysis and Vietnam, 1960s
  - The Cold War, 1970s–1980s
  - The Mideast Wars, 1990s–2005
  - The Mideast Wars and O.R. Reorganization, 2006–Present
  - Summary
  - References
- **APPENDIX 4. Organization of Operations Research in the U.S. Air Force**
  - The Air Force
  - Operations Research Analysts
  - Education for Operations Research
  - Air Force Organizational Alignment of Operations Research
  - Major Analytic Centers and Their Missions
  - RAND Project AIR FORCE
  - Air Force Management of Models and Simulation (M&S) and Studies
  - Summary

SECRETARY OF THE AIR FORCE
WASHINGTON

NOV 15 2016

Professor Brian Denton
2017 President
INFORMS
5521 Research Park Drive, Suite 200
Catonsville, MD 21228

Dear Professor Denton,

I am pleased to nominate the United States Air Force for the 2017 Institute for Operations Research and the Management Sciences (INFORMS) Prize.

Our nomination package highlights twenty operations research applications that had profound impacts: saving money and lives; improving efficiencies; and advancing the field of Operations Research with innovative techniques. It also includes endorsement letters from within the Air Force, U.S. and allied defense leaders, Members of Congress, academics, professional societies, and industry.

The United States Air Force has applied and advanced the principles of operations research for 75 years and will continue to lead into the future guided by what we have learned from the field. The impacts of advanced analytics and operations research continue to greatly improve the overall success of our United States Air Force and I hope that you agree that our accomplishments deserve the recognition of the INFORMS Prize.

Sincerely,

Deborah Lee James

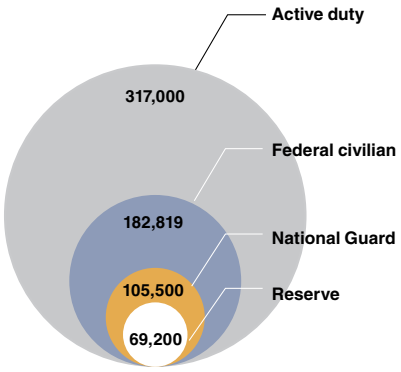
Summary

The U.S. Air Force Nomination for the 2017 INFORMS Prize

THE AIR FORCE IS A LARGE, COMPLEX ORGANIZATION with 317,000 regular (often called active duty) military members, 182,819 federal civilian employees, 105,500 National Guard members, and 69,200 military reservists.[1] As an organization, the Air Force rivals large corporations in terms of its complexity and its ability to harness the talent and spirit of its members. With a budget of $163.1 billion for fiscal year 2016, our leaders rely on approximately 539 military and 849 civilian operations research (O.R.) analysts serving in nearly 300 Air Force organizations to engender strong analytics and sound reasoning in all that we do for both the near and long term.

EXEMPLAR ACCOMPLISHMENTS From among our recent accomplishments based on O.R. applications, we highlight three exemplar topics:

- First, INFORMS awarded the 2006 Franz Edelman Prize to the Warner Robins Air Logistics Center for decreasing depot repair time for the C-5 Galaxy cargo aircraft from 360 to 250 days, which saves almost $50 million per year. These cargo aircraft have been credited with saving hundreds of soldiers' lives by reducing the need for land convoys in operations in Iraq and Afghanistan.
- Second, the Air Force, along with RAND Project AIR FORCE, has a long history in the development and advancement of strategic nuclear deterrence. Air Force analysts developed the integer program that supported the President's Nuclear Posture Reviews in 2002 and 2010. Additionally, the Military Operations Research Society awarded our analysts with the David Rist Prize for developing another technique to determine best forces, which supported the U.S. negotiators of the 2010 Strategic Arms Reduction Treaty.
- Third, Air Force analysts are leading the Department of Defense in transforming our test and evaluation of weapon systems through a design-of-experiments approach. Within the Air Force, testing costs $16 billion per year, and this design-of-experiment approach has reduced test durations and weapon consumption on various programs on the order of 80 percent.



U.S. Air Force Organization (Fiscal Year 2016 Budget)

In addition to these three exemplars, detailed later in this document, we provide an appendix that contains shorter summaries of 17 other O.R. applications that range across logistics, manpower, operational effectiveness, system acquisitions, and cost analysis.

ENDORSEMENTS Our excellence in O.R. has not gone unnoticed. This nomination includes a wide range of endorsements. The Honorable Deborah Lee James, Secretary of the Air Force, wrote our introduction. The Honorable Donald Rice, our former Secretary, provides his accolades. General Mark Welsh, our recent Chief of Staff, and General Larry Welch, an earlier Chief, describe their reliance on O.R. We have four endorsements from American defense leaders: Congressman Ted Lieu; the Honorable Dr. Harold Brown, former Secretary of Defense; the Honorable Eric Fanning, Secretary of the Army, and the Honorable Dr. Jamie Morin, director of the Cost Assessment and Program Evaluation organization in the Office of the Secretary of Defense. Each endorses the Air Force's use of O.R. From our allies, Mr. Alan Shaffer, director of North Atlantic Treaty Organization (NATO) Science and Technology, and Dr. Todd Mansell, chief of the Australian defense analysis, acknowledge our analytic excellence. Representing academia, Dr. Cynthia Barnhart, MIT professor and past INFORMS president, praises the Air Force's use of O.R. Mr. Thomas Denesia, president of the Military Operations Research Society, and Mr. Chris Arney, president of the Military Applications Society, acknowledge the history of Air Force O.R. awards and accomplishments. Three leaders from industry—Dr. David Chu, president of the Institute for Defense Analyses; Dr. Les Servi of MITRE; and Dr. Fred

[1] U.S. Air Force, *Fiscal Year 2017 Budget Overview*, SAF/FMB, February 2016, p. 24.

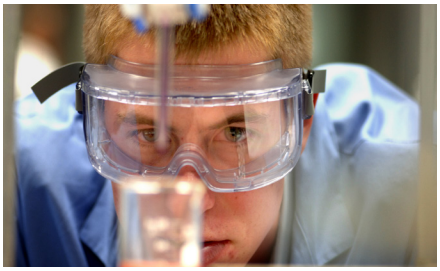
Glover, chief technology officer of OptTek Systems—each endorse the Air Force excellence in O.R. Their letters provide a range of perspectives and testimonies on the extent of our analytic capability and successes.

EDUCATION AND PUBLICATIONS The Air Force embodies technical education, including O.R. In 1919, just 11 years after the Wright Brothers flew the first powered flight, the Army Air Corps established the Air School of Application, which evolved into the Air Force Institute of Technology. Today, the Air Force Institute of Technology awards both master's and doctoral degrees in O.R. The U.S. Air Force Academy was one of the first universities to offer an undergraduate major in O.R.

The Air Force also advances scientific research. The U.S. Air Force Scientific Advisory Board (SAB), originally known as the Army Air Forces Scientific Advisory Group, was established by General Henry "Hap" Arnold in 1944 and chaired by his scientific advisor, Dr. Theodore von Kármán. For more than 70 years, the SAB has assisted the Air Force in maintaining its "vision into the future" of technology-enabled capabilities. In 1951, the Air Force created the research organization that today is called the Air Force Office of Scientific Research (AFOSR). AFOSR annually funds over 1,200 grants at more than 200 academic institutions and 250 industry research companies. From 2006 to 2014, AFOSR awarded an average of $33 million per year to O.R. projects, for a total of $298 million. These O.R. grants have generated almost 1,500 journal articles. Additionally, during the past ten years, the faculty at the Air Force Institute of Technology and the U.S. Air Force Academy have authored more than 79 academic O.R.-related publications per year.

AWARDS Over the years, Air Force O.R. analysts have been recognized for numerous awards, despite the fact that much of their works is classified and so cannot be disclosed. In 1957, Clayton Thomas and Walter Deemer won the Lanchester Prize. At least seven Air Force or RAND associates are INFORMS Fellows. From the INFORMS Military Applications Society (MAS), Jack A. Jackson, Gregory S. Parnell, Brian L. Jones, Lee J. Lehmkuhl, Harry Conley, and John Andrew won their Koopman Prize in 1996. J. Todd Hamill, Richard F. Deckro, Robert F. Mills, and James W. Chrissis also received this recognition in 2008. MAS also granted James Morris, an O.R. analyst at the National Air and Space Intelligence Center, its Bonder Scholarship. The Institute of Industrial and Systems Engineers named Lt Col J.D. Robbins the 2010 winner of the Pritsker Doctoral Dissertation Award.

The Military Operations Research Society (MORS) annually awards the David Rist



Prize for the best technical advance, which analysts from Headquarters Air Force have won in three of the past six years.

John Andrews, Patrick McKenna, and Karen Phipps won the 2010 award for their work on the Nuclear Posture Review and the follow-on Strategic Arms Reduction Treaty (START) negotiations with Russia. Saiful Hannan won the 2014 award for his analysis of Air Force active duty and reserve component force size for every weapon system with regard to demands, weapon system and manpower inventory, costs, employment policies, and risk. Brian Rose won the 2015 award for his analysis of the employment of land mines and alternative systems in conventional tactical situations.

Five Air Force and RAND Project AIR FORCE analysts have won MORS's Thomas Award, a key lifetime technical achievement award named after one of the early Air Force analysts, Clayton J. Thomas. These five analysts are Fellows of the MORS society. MORS started naming Fellows in 1989, and since then 22 current or former Air Force analysts have received this honor.

SUPPLEMENTAL MATERIAL SUMMARY

Air Force Contributions to the Foundations of O.R.

This appendix illustrates key foundations of O.R. that are rooted in Air Force support and involvement. The most famous Air Force support of O.R. was the 1947 task force named Project SCOOP (Scientific Computation of Optimal Programs). While working with Project SCOOP, Dr. George Dantzig developed the simplex method, which is listed as one of the top ten algorithms of the 20th century according to the *Journal Computing in Science and Engineering* (Vol. 2, No. 1, 2000). Besides linear programming, this appendix focuses on several seminal efforts in network modeling, dynamic programming, game theory, simulation and statistics, cost analysis, and production and inventory control.

Additional O.R. Examples

This appendix describes an additional 17 wide-ranging recent applications of O.R. in the Air Force. The topics are organized into five areas: logistics and infrastructure, manpower analysis, operational effectiveness, acquisition of new systems, and cost analysis.

History of O.R. in the Air Force

British scientists coined the term "operational research" during World War II. In 1942, General Carl Spaatz, commander of the England-based VIII Bomber Command, established an O.R. unit. Before the end of that year, General Henry "Hap" Arnold, Commander of the Army Air Forces, formed O.R. units in the Air Staff and in each major command, which were among the first O.R. organizations in the United States. After World War II, General Arnold co-founded Project RAND, and RAND Project AIR FORCE continues the original project's legacy of analysis for the Air Force. As previously mentioned, Dr. George Dantzig was working on large-scale logistic planning optimization as an Air Force employee in 1947. In 1951, the Air Force installed the first computer in the Pentagon to solve such mathematical problems. From its foundation O.R. was woven into the Air Force fabric and continues today.

When World War II ended, the Ford Motor Company hired a group of former Army Air Forces analysts, including Robert S. McNamara, as "whiz kids" who transitioned O.R. from the Air Force to industry. When President Kennedy appointed McNamara as Secretary of Defense, he hired from RAND a new generation of "whiz kids" into the Office of the Secretary of Defense. Their initiatives expanded the application of O.R. from improving current military actions to providing foundations for decisions on the acquisition of future warfighting systems.

In the Oval Office, President John F. Kennedy meets with Secretary of Defense Robert S. McNamara and Chairman of the Joint Chiefs of Staff Gen. Maxwell D. Taylor (far left).

RAND developed software and programming languages to enable early computers, such as the 1950s-era IBM pictured above, to analyze complex research problems for the Air Force.

After consolidating our O.R. units to share mainframe computers in the 1960s and 1970s, in 2006, the Air Force returned to the original World War II organization, in which each major command and Number Air Force commander has a direct subordinate responsible for O.R., ensuring that high-quality, relevant analysis is readily available to guide major decisions. Again, the Air Force deployed "combat analysts"—very similar to the original operations researchers in World War II—to Iraq and Afghanistan to identify and help solve problems.

Organization of O.R. in the Air Force

The organization appendix provides information on Air Force analysts, education, and organization. The Air Force, along with RAND Project AIR FORCE, has strategically and effectively integrated O.R. throughout its structure. The Air Force maintains a career field of military analysts, ranging from lieutenants to colonels, and complements them with career government civilian analysts. The Air Force's educational institutions offer bachelor's, master's, and doctoral degrees in O.R., and the Pardee RAND Graduate School offers Ph.D.'s in policy science with an O.R. specialization. Our headquarters directorate Studies, Analyses, and Assessments manages our studies and guides model development throughout the Air Force.

Exemplar Operations Research Topics in the U.S. Air Force

No.1 Warner Robins Aircraft Repair and Overhaul

THE C-5 GALAXY is the largest and one of the oldest aircraft in the U.S. Air Force, with an in-service date of 1969. Its unique capabilities directly impact operations worldwide, supporting the first pillar of the Air Force mission "Global Reach, Global Power, and Global Vigilance."

Sustained operations in increasingly austere environments with decreasing budgets put an enormous strain on the entire military transportation network, and O.R. has proved invaluable in saving time, money, and ultimately lives and continues to have a significant positive impact today.

Keeping this stalwart of strategic airlift relevant and viable for decades has required innovative ideas in maintenance, logistics, and operations. To improve the availability of C-5s, "Critical Chain" project management informed by key analytics was implemented and decreased time in depot from 360 days to less than 250 days. Since 2006, continuous adherence to the research findings has further reduced time in depot to just 160 days and returned five C-5s to the scarce inventory. INFORMS recognized this innovative analysis and its tangible, real-world impacts with the Franz Edelman Prize in 2006.[1] More accolades came that year when Warner Robins received the Shingo Prize for Excellence in Manufacturing—deemed the Nobel Prize for manufacturing by *BusinessWeek*—and was also honored as a Shingo Prize Public Sector Gold award recipient.[2] Moreover, cost savings amounted to $49.8 million in the first year, with savings accelerating to over $350 million by 2009. Besides benefiting taxpayers, strategic mobility planners could optimize the airlift option with greater confidence.[3]

This innovative analysis and its real-world impacts earned Warner Robins both the **Franz Edelman Prize** and **Shingo Prize Public Sector Gold** award in 2006.

The proliferation of improvised explosive devices (IEDs) has taken many American, coalition, and civilian lives, with nearly two-thirds of all U.S. casualties in Iraq and Afghanistan attributable to IEDs.[4] The relentless threats to exposed surface transportation networks in Iraq and Afghanistan forced commanders to rely heavily on airlift to get vulnerable convoys off the road.[4,5] While difficult to quantify, there is little doubt that the shift to airlift has saved hundreds of lives in the past decade.[6] System-wide adaptation has also resulted in demonstrable savings in time and costs.

The C-5 Galaxy has been the backbone of global U.S. operations for nearly 50 years. This would not have been possible without innovations in maintenance, logistics, and operations provided by O.R.

Change is never easy—especially in entrenched sectors such as military logistics, with its decades-old culture of depot maintenance and overhaul. Still, the Air Force soon expanded the use of Critical Chain project management analytic techniques and tools to other airframes, such as the C-130 and C-17, which freed up 11 dock spaces that accommodated additional work worth $65 million in just 2006. Other Air Force logistics centers also adapted the methodologies and almost immediately realized similar cost savings and increased system availability.

[1] Mandyam Srinivasan, William D. Best, and Sridhar Chandrasekaran. "Warner Robins Air Logistics Center Streamlines Aircraft Repair and Overhaul." *Interfaces*, Vol. 37, No. 1 (2007): 7-21.

[2] "Edelman Winner Adds Shingo Prize." *Operations Research & Management Science Today*. August 2, 2006. http://www.orms-today.org/enews/fr0806c.html

[3] Dr. Gerald G. Brown, Dr. Matthew Carlyle, and Dr. Robert F. Dell. "Optimizing Intratheater Military Airlift in Iraq and Afghanistan." *Military Operations Research*, Vol. 18, No. 3 (2013): 52. http://faculty.nps.edu/dell/docs/brown_18.pdf

[4] Gregg Zoroya. "How the IED Changed the U.S. Military." *USA Today* (online): http://www.usatoday.com/story/news/nation/2013/12/18/ied-10-years-blast-wounds-amputations/3803017/

[5] Rochelle Sollars, 19th Airlift Wing Public Affairs (online): http://www.amc.af.mil/News/Article-Display/Article/146436/777th-eas-removes-20000-vehicles-from-roads/

[6] Tim Ripley. "*Middle East Air Power in the 21st Century*," Pen and Sword-Aviation (2010): 436.

No. 2 Post–Cold War Nuclear Deterrence Analysis

THE AIR FORCE WITH RAND PROJECT AIR FORCE have a long history of successfully applying O.R. to nuclear deterrence and warfare. RAND was key to developing the Air Force's nuclear deterrence strategy throughout the formative years of the Cold War in the 1950s and 1960s. Lieutenant General Glenn Kent's memoir, published by RAND in 2008,[1] describes the application of game theory to the confrontation between the United States and the Soviet Union to determine nuclear weapon quantities necessary for deterrence.

Confirming the efficacy of a nuclear war strategy is certainly impractical in the real world; thus, reliance on modeling and analysis is the only option to buttress sound military judgment. During the 1980s and 1990s, the Air Force used the Arsenal Exchange Model, a multi-objective linear program, to evaluate potential nuclear exchanges and treaty positions.[2] In the 2000s, Air Force analysts developed an integer program, the Weapon Assignment Model,[3] that accounts for nonlinear geographic dispersion of ballistic missile warheads in nuclear warfare. Analysts used this model to support hundreds of billions of dollars of force modernizations in bombers and intercontinental and sea-launched ballistic missiles. The results were presented across the Defense Department, provided the analytic foundation for the President's Nuclear Posture Reviews in 2002 and 2010, and impacted the Nuclear Weapons Employment Strategy in 2013. The Weapon Assignment Model became the prototype of a new U.S. Strategic Command planning system likely to serve future presidents' national defense strategies.

MORS recognized the Air Force's innovative nuclear force structure analysis with the prestigious 2010 David Rist Prize for best technical advance in O.R.

After winning the Cold War, a decline in defense spending forced analysts in the Air Force and U.S. Strategic Command to partner and co-develop an innovative analytical tool that indicates the best force structure. Senior diplomats and U.S. arms control negotiators leveraged the analysis informed by this tool to broker a new Strategic Arms Reduction Treaty in 2010. Later that year, MORS recognized that innovative technique as the best technical advance in O.R. with its prestigious 2010 David Rist Prize.

In 2012, the Joint Chiefs of Staff reexamined the need for a strategic triad of bombers, submarines, and intercontinental missiles in the face of looming budgetary pressure. The Air Force contended that the bombers' contributions to assurance and deterrence were grossly undervalued. Air Force analysts applied factor analysis validating the worth of the bomber and the nuclear triad across 22 scenarios—and the Secretary of the Air Force credited their results with changing discussions in the White House. In 2014, as the President considered further reductions, Air Force analysts leveraged previous O.R. efforts and prepared an analytical framework to evaluate strategic deterrence to inform the right-sizing debate of the multi-billion-dollar, no-fail nuclear deterrence mission.[4]

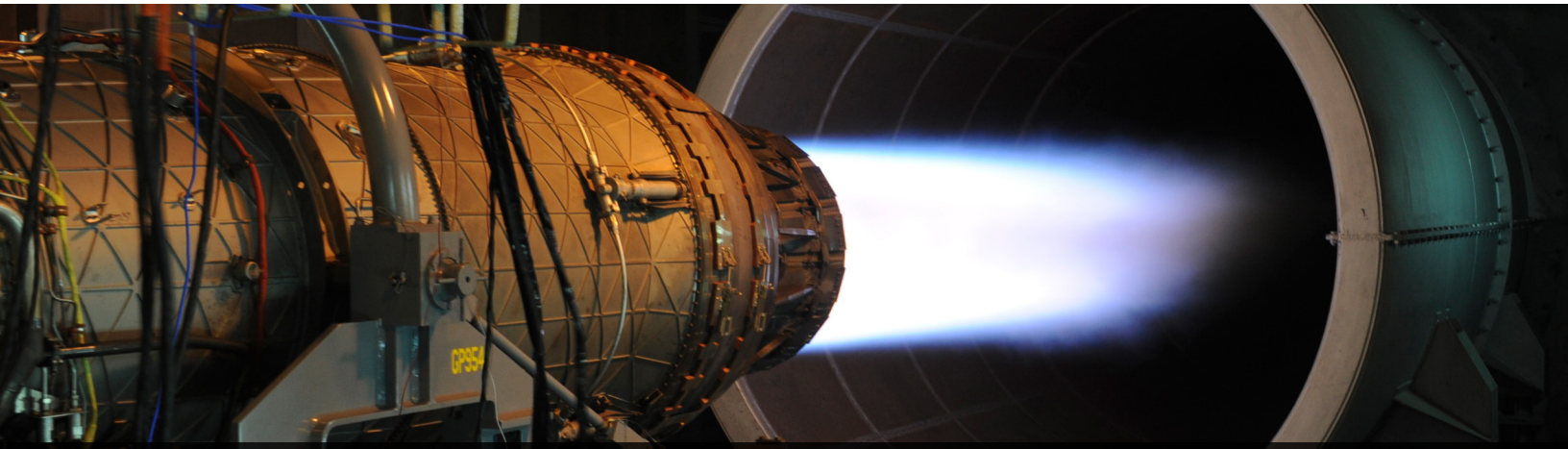
A B-2 Spirit bomber refuels over the Pacific Ocean. The Air Force relies on modeling and simulation to determine the right mix of bombers and other assets to support America's nuclear deterrence.

[1] Glenn A. Kent, Michael Spirtas, and Bruce Pirnie. *Thinking About America's Defense: An Analytical Memoir.* RAND/OP-223. RAND Corporation, 2008. www.rand.org/t/OP223

[2] Douglas W. Owens, Gregory S. Parnell, Robert L. Bivins. Strategic Arms Reduction Treaty (START) Drawdown Analyses. *Operations Research*, Vol. 44, No. 3 (1996): 425-434.

[3] Christopher A. Cullenbine, Mark A. Gallagher, and James T. Moore. "Assigning Nuclear Weapons with Reactive Tabu Search." *Military Operations Research*, Vol. 8, No. 1 (2003): 57-69.

[4] Mark A. Gallagher and Justin E. Sorice. "Considering Alternative Nuclear Targeting Strategies." *Comparative Strategy*, Vol. 33, No. 5 (2014): 451-465.



No. 3 Transforming Defense Testing Using Design of Experiments

THE FOOTPRINT OF THE MILITARY TEST AND EVALUATION (T&E) enterprise is substantial: Each new weapon system must, by law, undergo trials. The Air Force initiated and is leading a large-scale effort in the Department of Defense to replace the current hodgepodge of ad hoc test methods with a scientific and statistically rigorous approach using Design of Experiments (DOE).

The Air Force Operational Test and Evaluation Center (AFOTEC) routinely uses DOE, and its track record of success validates that DOE is more than relevant—it is essential to test excellence. Uniquely designed experiments span multidimensional battlespaces, minimize cost, and control the risk of fielding flawed systems.

The Air Force's use of DOE was directly credited with a breakthrough in the development of the Joint Air to Surface Standoff Missile, where nearly $7.2 million and 60 days of testing were saved while reducing the number of missiles from 21 to 16. Following that application, AFOTEC institutionalized use of DOE across the Air Force. Based on AFOTEC's initiative, the Director, Operational Test and Evaluation (DOT&E), a presidential appointee, adopted the Air Force's best practice and made it a Defense Department standard.[2] Other successes include reduction of up to 88 percent of design points to test the results of high-pressure engine inlet on the F-16 fighter; 40 percent savings in static tests of ejection seats; 80 percent reduction in the total number of simulated shots to span range/angle/aspect grid to prove performance of the AIM-9X air-to-air missile; reduction from 35 to 4 fuses to confirm successful refurbishment; and 75 percent reduction in test cost and schedule for weekly upgrade testing of electronic warfare emitters.[1] DOE aids correct combat capability decisions while ensuring thrift in an era of austere defense budgets.

Air Force proponents of DOE have received numerous awards, including the Secretary of the Air Force's Decoration for Exceptional Civilian Service in 2008 and the American Society for Quality's Bisgaard Award in 2013.

DOE's career impacts on other activities are equally compelling. Military and civilian Air Force analysts are trained in and successfully employ DOE across the range of Air Force activities. From conducting operational and developmental tests, to large-scale military exercises, to basic scientific research in ten laboratories, DOE is transforming the way data are collected to inform decisions. And, although the soul of DOE is nearly 100 years old, graduate research challenges remain.[3] The Defense Department chartered a DOE Research Consortium of eight universities, including the Air Force and Navy graduate schools, Virginia Tech, Arizona State, and Georgia Tech. Consortium students gain firsthand front-line experience and are often hired by AFOTEC to implement research findings.

Ultimately, the purpose of T&E is to manage risks and rapidly mature system designs by finding defects early, ensuring that systems are mission-capable at a significantly reduced cost.[5] DOE has given Air Force analysts a seat at the table whenever data are being gathered and analyzed, such as with the $500 million comprehensive F-35 test, where the test design will save 30 percent of the original test cost. From sophisticated Monte Carlo simulations of war and campaigns, to developmental and operational tests, a third of Air Force analysts are involved in testing in some capacity. Exercising skill in the design and analysis of experiments with DOE is becoming ubiquitous in defense test and analyses.

[1] Statistical Test Optimization Panel, NDIA Conference on Systems Engineering. "Design of Experiments: Transforming Test from Design to Fielding" (January 2013).

[2] J. M. Gilmore, "Guidance on the Use of Design of Experiments (DOE) in Operational Test and Evaluation, Memorandum." Office of the Director, Operational Test and Evaluation (2010).

[3] The Joint Staff. "Research, Development, Test & Evaluation, Defense Wide, FY 2008/2009 Budget Estimates," Vol. 1.

[4] R. A. Fisher, *The Design of Experiments.* Edinburgh, Scotland: Oliver and Boyd (1935).

[5] R. T. Johnson, G. T. Hutto, J. R. Simpson, and D. C. Montgomery. "Designed Experiments for the Defense Community," *Quality Engineering,* Vol. 24, No. 1 (2012): 60-79.

Endorsements

Diverse leaders representing multiple sectors have endorsed the Air Force's implementation of operations research.

U.S. AIR FORCE LEADERS

The **Honorable Deborah Lee James,** Secretary of the Air Force, has endorsed our nomination package. The **Honorable Donald Rice,** also an analyst, comments on his time as Secretary of the Air Force during the end of the Cold War (1989–1993). The highest-ranking general in the Air Force is the Chief of Staff of the Air Force (CSAF). **General Mark A. Welsh III,** CSAF until June of 2016, summarized O.R. impacts during his four years of leadership along with his 40 years of military service. **General Larry D. Welch (retired),** the 12th CSAF (1986–1990), describes his work as an analyst determining fighter procurements.

CONGRESS AND (U.S. AND ALLIED) DEFENSE LEADERS

Several defense leaders note the extent of the Air Force's commitment to O.R. **Congressman Ted Lieu**, House Committee on Oversight and Government Reform, Subcommittee on National Defense, comments on the value of Air Force analysis, including RAND reports. The **Honorable Dr. Harold Brown**, former Secretary of Defense, describes the value of Air Force analysis. The **Honorable Eric K. Fanning,** Secretary of the Army, who was previously a leader in both the Navy and Air Force, notes the excellences of the Air Force's approach to O.R. The **Honorable Dr. Jamie Morin**, director of Cost Assessments and Program Evaluation in the Office of Secretary of Defense, traces his organization's roots to when Secretary McNamara brought in the "whiz kids" from RAND in 1961.

From our allies, **Mr. Alan R. Shaffer,** director of NATO's Science and Technology Collaboration Office, cites the extent of U.S. Air Force analysis. **Dr. Todd Mansell,** chief of the Joint and Operations Analysis Division of Australian Defence Department's Strategic Policy and Intelligence Group, cites his collaboration with U.S. Air Force Studies, Analyses, and Assessments.

ACADEMIA AND PROFESSIONAL SOCIETIES

Our endorsement from **Dr. Cynthia Barnhart,** chancellor of the Massachusetts Institute of Technology (MIT) and former president and Fellow of INFORMS, notes the education and sophistication of Air Force analysts. **Mr. Thomas Denesia,** president of the Military Operations Research Society, and **Mr. Chris Arney,** president of the Military Applications Society, note the recognition and awards won by Air Force analysts.

INDUSTRY

Three leaders from industry endorse the Air Force excellence in O.R. **Dr. David Chu,** president of the Institute for Defense Analyses, and **Dr. Les Servi** from MITRE cite the Air Force's analytic prowess. **Dr. Fred Glover,** chief technology officer at OptTek Systems, Inc., and Fellow of INFORMS, acknowledges working with extraordinarily bright and creative Air Force O.R. professionals over a span of nearly 50 years.

DONALD B. RICE
10126 EMPYREAN WAY #103
LOS ANGELES, CA 90067

August 22, 2016

Dr. Brian Denton
President-Elect, Institute for Operations Research
and Management Science (INFORMS)
5521 Research Park Drive, Suite 200
Catonsville, MD 21228 USA

Dear Professor Denton:

I write to strongly endorse the application of the United States Air Force for the INFORMS Prize in 2017. Speaking as an INFORMS Fellow of long standing, I can state without reservation that the Air Force embodies the attributes that INFORMS seeks for our highest honor: an "organization that has repeatedly applied the principles of advanced analytics and OR/MS in pioneering, varied, novel, and lasting ways."

It has been my privilege to observe the Air Force's operations research and analysis enterprise from multiple vantage points during my career. The Air Force provided the vital initial spark that created the RAND Corporation, an organization I had the honor to lead and that has served as continual source of operations research innovation and leadership for the nation and the world. Throughout the intervening decades, the Air Force has been the most consistently creative and open client for RAND's research. Air Force leaders are data-driven, analytically minded, and committed to continuous improvement, and that commitment is evidenced by their sponsorship and reliance on high-quality analysis from both external and internal sources.

My four years as Secretary of the Air Force were a time of transformation for the nation and the service. The Cold War ended, and the U.S. fought its first post-Cold War conflict, restoring the territorial integrity of Kuwait. Transformative modernization activities such as the B-2 bomber and the F-22 fighter were pursued while the Air Force dramatically reduced its budget through both aircraft inventory and manpower reductions. Balancing these multiple priorities would not have been possible without an enterprise-wide analytic community that was able to rapidly respond with solutions to complex troop and force deployments, intelligence production, combat sortie generation, evacuation of casualties and non-combatants, and many, many more vital considerations.

After Operations Desert Shield and Desert Storm, the Air Force worked hard to maintain and improve its operations research and management science skills. Building on a foundation of existing talent, we created the Air Force Studies and Analysis Agency at the headquarters and expanded the number of undergraduate and graduate OR/MS degrees available to Air Force

officers through, among other sources, the Air Force Institute of Technology, a premier operations research program in its own right. I have worked with many large organizations, both public and private. I can say confidently that the Air Force is premier among all of them in creatively and effectively using the tools of operations research to make the most informed and powerful decisions at the highest levels.

In 1942, General Hap Arnold first formed an operations research staff at Headquarters Air Force. What could be more fitting than to recognize the Air Force's long-standing excellence and achievements in 2017, the 75th anniversary of that farsighted decision? Please join with me in congratulating the Air Force on their decades-long quest for excellence and award them the 2017 INFORMS Prize.

Sincerely:

The Honorable Donald B. Rice, Ph.D.

Secretary of the United States Air Force, 1989 – 1993

President and CEO, RAND Corporation, 1972 – 1989

President, Institute of Management Sciences, 1975-1976

DEPARTMENT OF THE AIR FORCE
OFFICE OF THE CHIEF OF STAFF
UNITED STATES AIR FORCE
WASHINGTON DC 20330

JUN 10 2016

HQ USAF/CC
1670 Air Force Pentagon
Washington, DC 20330-1670

Professor Brian Denton
5521 Research Park Drive, Suite 200
Catonsville, MD 21228-4860

Dear Professor Denton:

I strongly recommend you consider the United States Air Force for the 2017 Institute for Operations Research and the Management Sciences (INFORMS) Prize. During my forty years as an American Airman, I witnessed operations research firsthand…in every facet of our business.

From factories to flight lines and concepts to constellations, operations research underscores every step we take toward safeguarding our Airmen, our allies, and our assets. Operations research guided the Jolly Green Giants who rescued countless comrades in Vietnam, facilitated the partnership between Project RAND and 32 Nobel Alumni, changed the Air Force way of war in Operation DESERT STORM, and continues to stretch our comfort zone in every possible way.

I'm unspeakably proud of our 660,000 Airmen. Please join me in recognizing their extraordinary, global contributions by honoring them with the prestigious INFORMS Prize.

Sincerely,

Mark Welsh

MARK A. WELSH III
General, USAF
Chief of Staff

Dear Professor Brian Denton, 2017 INFORMS President,

It is my distinct pleasure to recommend the United States Air Force for the 2017 INFORMS Prize.

During my four years as the Air Force Chief of Staff, major decisions made at Headquarters and at our Major Commands were informed by expert Air Force analysts, who relied heavily on operations research techniques to analyze, model and solve problems. Hundreds of civilian and military professionals brought vital expertise to the Air Force's decision making process.

I learned these skills under Lieutenant General Glenn Kent while serving in the Air Force Studies and Analyses organization and practiced them as we developed and implemented the acquisition strategy for the combined F-15 and F-16 fighter force. Later, I applied gap analysis to operational shortcomings—a process that led to the development of the F-117 stealth fighter and the F-15E all-weather, precision strike fighter fleet. Over 16 years as President of the Institute for Defense Analyses, I observed these same analytic processes guiding major Air Force decisions.

I wholeheartedly endorse the United States Air Force for this prestigious award. Thank you for your consideration.

Larry D. Welch, General (Retired), USAF
Chief of Staff of the United States Air Force, 1986 – 1990

TED W. LIEU
33RD DISTRICT, CALIFORNIA

COMMITTEE ON THE BUDGET

COMMITTEE ON OVERSIGHT
AND GOVERNMENT REFORM

415 CANNON HOUSE OFFICE BUILDING
WASHINGTON, DC 20515
(202) 225-3976

5055 WILSHIRE BOULEVARD, SUITE 310
LOS ANGELES, CA 90036
(310) 652-3095

1600 ROSECRANS AVENUE, 4TH FLOOR
MANHATTAN BEACH, CA 90266
(310) 321-7664

Congress of the United States
House of Representatives
Washington, DC 20515–0533

October 19, 2016

Professor Brian Denton
2017 INFORMS President
Institute for Operations Research and Management Science (INFORMS)
5521 Research Park Drive, Suite 200
Catonsville, MD 21228

Dear Professor Denton:

I am pleased to give my highest recommendation to our U.S. Air Force for the 2017 INFORMS Prize.

I represent California's 33rd congressional district. As a member of the House Committee on the Budget, I review all the Department of Defense (DoD) budget initiatives along with their analytic support. The quality of the Air Force reports clearly demonstrates the Air Force's commitment to fact-based analyses and assessments to resolve DoD issues.

My district is home to many great American companies and nonprofits, including the RAND Corporation. RAND's Project AIR FORCE is the only Studies and Analyses project at a federally funded research and development center (FFRDC) dedicated solely to supporting the United States Air Force. Air Force analyses greatly are enhanced by RAND's independent reports and result in impressive insights in the testimonies of Secretary James and Chief of Staff General Goldfein.

As you consider the finalists for your esteemed 2017 INFORMS Prize, I offer my strong support to the outstanding analytic accomplishments of our United States Air Force.

Sincerely,

Ted W. Lieu

Ted W. Lieu
Member of Congress

PRINTED ON RECYCLED PAPER

8/19/2016

Dr. Brian Denton
President-Elect, Institute for Operations Research
and Management Science (INFORMS)
5521 Research Park Drive, Suite 200
Catonsville, MD 21228 USA

Dear Professor Denton:

It is my great pleasure to strongly recommend the United States Air Force for the 2017 INFORMS Prize.

My association with the Air Force and its operations research and analysis community stretches back to 1950's. As a Project Manager in 1953, later as Division Leader and then Director of Lawrence Livermore Laboratory, I worked with RAND and Air Force scientists (including then Lt. Col. Lew Allen, later Chief of Staff of the Air Force) and operations analysts on the effects of nuclear weapons. In the mid-1950s Livermore, and I as its representative, was part of the Minuteman team (TRW as SETD, the Air Force's Western Development Division -WDD-as program manager) responsible for integrating the nuclear warhead with the reentry vehicle to optimize military effectiveness. Then in the 1960s as Director of Defense Research and Engineering (DDRE) and then as Secretary of the Air Force, I worked with Air Force leadership to significantly increase the breadth and application of systems analysis in the Air Force. At the time, our military analysis capability had been depleted as analysts left military service after World War II (a shift that helped to successfully transform post-war American industry). A trusted colleague during this period was Air Force Lt. Gen. Glenn Kent, who had as a Lieutenant Colonel been the leading analyst at WDD, and who led the institutionalization of operations research in the Air Force as Director of Air Force Studies and Analyses. It was in DDRE that Kent had led the study which produced the concept of "assured destruction" as the criterion for the capabilities of U.S. strategic forces.

By the time I returned to the Department of Defense as its Secretary in the 1970's, Glenn had moved on to the RAND Corporation, that institution itself a notable Air Force accomplishment. In his wake, I found at the Air Force solid analytics underpinning the triad of nuclear deterrence, the strategic tanker and transportation fleets, and acquisition plans for the world's premier fighter force – critical elements of our national security posture.

The Air Force has continued its leadership in analytic decision making by training its leaders and staff members in operations research methods. For example, the U.S. Air Force Academy was a finalist for the 2016 INFORMS UPS George D. Smith Prize for their effective and innovative OR academics, and the Air Force Institute of Technology is publishing over 100 scholarly papers per year – a resource for the nation.

I continue to observe with pleasure the depth and soundness of analysis supporting Secretary James and General Goldfein as they explain the rationale for Air Force plans and programs in their Congressional testimony. This clear indication of the continued excellence of the Air Force analytic enterprise provides yet another telling reason to award our United States Air Force the 2017 INFORMS Prize.

Sincerely,

Harold Brown

SECRETARY OF THE ARMY
WASHINGTON
SEP 13 2016

Professor Brian Denton
President-Elect
INFORMS
5521 Research Park Drive, Suite 200
Catonsville, MD 21228

Dear Professor Denton:

I am pleased to endorse the nomination of the United States Air Force for the 2017 INFORMS Prize.

I have had the honor and privilege of serving as a senior leader for the Navy, Air Force, and now the Army. As the Under Secretary, Chief Management Officer, and Acting Secretary of the Air Force, I was extremely impressed with the institutionalized practice of thorough analyses in the Air Force planning, programming, budgeting and execution process. In accordance with recommendations from Air Force analyses, we successfully managed a 13 percent budget cut during my first year by aggressively reducing costs in programs to preserve critical capabilities. I attribute much of the success we had in this difficult period to the insight of early Air Force leaders and their successors who organized analytic resources to make a permanent contribution to the decision-making process.

The Air Force has an outstanding and integrated approach to applying operations research throughout the organization. I give my highest recommendation to the United States Air Force for your prestigious INFORMS Prize.

Sincerely,

Eric K. Fanning

Eric K. Fanning

OFFICE OF THE SECRETARY OF DEFENSE
1800 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-1800

COST ASSESSMENT AND
PROGRAM EVALUATION

AUG 12 2016

Dear Professor Brian Denton,

It is my pleasure to support the United States Air Force for the 2017 INFORMS Prize. The Air Force has prioritized developing world-class analysts and adopting analytic methods and data collection to support the most efficient allocation of scarce taxpayer dollars. The Air Force is fostering an environment that emphasizes analytical investigations to drive decisions based on data and evidence rather than loyalty and opinion.

I believe that I am uniquely qualified to assess the Air Force's use of operations research in decision making as I've been both an internal and external user of their analysis. During my five years as the Assistant Secretary for Financial Management and Comptroller, I was responsible for all financial matters of the Air Force, including cost analysis, financial management and budgets. In this role, and as the acting Under Secretary of the Air Force, I relied on analysis produced by Air Force operations research analysts to support our decision-making process. Specifically, operations research was vital to shaping the force during the Budget Control Act (BCA) drawdown and building focused acquisition programs that solve key military problems at an affordable cost. Overall, I was impressed with the degree of influence that operations research had within the Air Force writ large.

In my current role as the Director of Cost Assessment and Program Evaluation (CAPE), the successor organization to the original Systems Analysis office, I lead an organization tasked with providing the Secretary and Deputy Secretary of Defense with independent analysis on the Department's plans, programs, and budgets. We are on the receiving end of Air Force plans. The Air Force's commitment to fact-based analyses and assessments is evident in its Analyses of Alternatives (AoAs), which are the underpinning for ensuring cost effective materiel solutions to requirements. A recent example that CAPE reviewed was a thorough and well-reasoned AoA to destroy hard and deeply buried targets. The analysis informed programmatic investments in munitions, platforms, and intelligence, surveillance and targeting capabilities.

In conclusion, the United States Air Force would be an excellent choice to be the recipient of the 2017 INFORMS Prize. The Air Force is currently faced with significant budgetary pressures in multiple areas and will continue to depend on rigorous analysis from its operations research analysts. I'm happy to discuss my endorsement further and can be reached at (703) 697-5770.

Sincerely,

Jamie Morin
Director

SCIENCE AND TECHNOLOGY ORGANIZATION

Office of the Director

CSO/DIR(2015)2021

6 June 2016

Professor Brian Denton
2017 INFORMS President

Dear Professor Brian Denton, the 2017 INFORMS President

I am very pleased to endorse the nomination of the United States Air Force in their request for the INFORMS Prize in 2017.

The US Air Force is a tremendously innovative and creative organization when it comes to Operations Research. In my time as the Assistant Secretary of Defense for Research and Engineering, I witnessed this innovation first-hand. The Air Force formed one of the first headquarters organization dedicated to advanced operations research (OR) analysis through the creation of the "A-9", the Directorate for Studies, Analyses and Assessments, Headquarters U.S. Air Force and, subsequently, created dedicated operational analysis divisions in most major commands. These directorates and divisions conduct in-depth analysis used in the Air Force decision process, as well as manage the career-development programs for their military and civilian analysts. They also conduct ground-breaking use of modeling and simulation in their decision-making and strategic planning and budgeting efforts - the US Air Force is truly on the cutting-edge of OR as a field of study and practice. I watched with particular interest the way the Air Force integrated OR into major decisions concerning the Long Range Strike and Space Analysis of Alternatives. The A-9 led the Department's thinking on how to reduce fuel costs to the battlefield through very intensive analysis of the fuel supply chain. These are but three recent examples of the leadership the Air Force has shown in OR; the list could go on for pages, but the key theme is the leadership in OR applications shown by the Air Force.

Now that I am at NATO working with scientists from around the globe, I draw upon my experiences both as Assistant Secretary and as an on-the-ground analyst for the Air Force. Those experiences, and how I am able to use them in support of NATO's missions today, are testaments to how impressive and enduring USAF's dedication is to OR.

I unreservedly join others in recommending the 2017 INFORMS Prize be awarded to the US Air Force in light of the organization's continuous dedication to the field of study and its use of OR methods and tools in both high-level strategic decision-making and day-to-day efficiency and effectiveness efforts.

Sincerely

Mr. Alan Shaffer
Director, NATO Collaboration Support Office

BP 25 - F-92201 Neuilly-sur-Seine Cedex - France
Tel: +33 (0)1 55 61 22 00 - Fax: +33 (0)1 55 61 22 99 - E-Mail : mailbox@cso.nato.int

Australian Government
Department of Defence
Strategic Policy and Intelligence Group

Strategic Policy and Intelligence

R2-3-113
PO Box 7902
Russell Offices
Canberra ACT 2600
Australia

Tel: +61 2 6265 2041

FAS SP&I I/OUT/2016/003
21 June 2016

Dear Professor Edward H. Kaplan, INFORMS President

It brings me great pleasure to offer my endorsement to the nomination of the United States Air Force for the 2017 INFORMS Prize.

Until recently I led operations research and analysis for the Australian Vice Chief of Defence Force Group, Joint Operations Command, and the Strategy Executive. We find that the US Air Force analysis centers are exceptionally innovative and we seek opportunities to collaborate with them in advancing our analytic techniques. Here are three examples: First, the Air Force Research Laboratory is advancing a simulation environment that enables easy scenario development and new system instantiation along with collaboration and sharing through library features. Second, we are collaborating with US Air Force analysts on developing the next fighter aircraft engagement simulation. A key aspect of this new simulation is modeling pilot perceptions and reactions. Third, we are collaborating to develop an enterprise model that examines potential future aircraft combinations simultaneously in varying scenarios. The US Air Force's innovative approach captures the outcome variability, usually modeled through Monte Carlo replications, through a Bayesian Network. We assess the US Air Force operations research capability to be a world class innovative military modelling and analysis organisation. They are advancing analytics in the defense operations research community.

Additionally, the Australian Department of Defence would highlight the enormous strategic value the US Air Force gains from their analysis organisations containing combat operators that are aligned as direct reports to commanders. Through this strong engagement they can routinely deliver their insights to the most senior decision makers.

I emphatically encourage you to select the US Air Force for your internationally renowned INFORMS Prize!

Yours sincerely

Dr Todd Mansell, PhD
First Assistant Secretary Strategic Policy and Intelligence - Initiatives
Department of Defence
Canberra, Australia

***Defending Australia** and its National Interests*

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cynthia Barnhart, *Chancellor*
Ford Professor of Engineering

77 Massachusetts Avenue, Building 10-200
Cambridge, Massachusetts 02139–4307
Phone: 617–253–3815
Fax: 617–253-8833
cbarnhart@mit.edu

September 12, 2016

Professor Brian Denton
2017 INFORMS President
Department of Industrial and Operations Engineering
1205 Beal Avenue
Ann Arbor, MI 48109-2117

Dear Professor Denton,

It is my pleasure to add my endorsement to what surely will be a chorus of enthusiasm as the US Air Force vies for the 2017 INFORMS Prize.

Over my career and during my time as President of INFORMS, I had the pleasure of working closely with numerous Air Force operations research professionals. The breadth of expertise and their large numbers are testament to the Air Force's serious commitment to operations research.

Hundreds of OR professionals make their way through the United States Air Force Academy, the Air Force Institute of Technology, and Air Force-sponsored civilian academic programs, amassing more than 100 publications each year. The development of a corps of ready and competent OR analysts demonstrates the importance the Air Force places, not only on outstanding analysis and assessment, but on the institutionalization of the field of study within its ranks.

Many great organizations emphasize OR to better their efficiency and effectiveness, yet the Air Force is unique in its long-term dedication to developing its team members, benefitting both the institution and its people. This constant focus on professional education and expansion of perspectives has yielded tremendous institutional advancement for the Air Force and has entrenched an appetite for fact-based decision-making among its most senior leaders.

As these world-class analysts transition to other careers, industry and other agencies benefit from their outstanding education and experiences while in the Air Force. This ripple effect can only come from an organization that is so dedicated to the development of OR, both as a career for its members and as an underlying tool for its own success.

I urge you to recognize the Air Force with the 2017 INFORMS Prize for their contributions and leadership within our field.

Sincerely,

Cynthia Barnhart

Cynthia Barnhart
Chancellor
Ford Professor of Engineering

Professor Brian Denton
2017 INFORMS President Elect
INFORMS
521 Research Park Drive, Suite 200
Catonsville, MD 21228

Dear Professor Denton,

As Presidents of the Military Operations Research Society (MORS) and the Military Applications Society (MAS), it is our pleasure to endorse the US Air Force nomination for the 2017 INFORMS Prize.

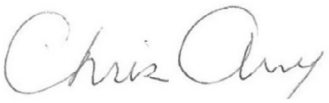
We are very familiar with not only the rich history of operations research work within the Air Force but also the organization's dedication to OR as a career field for its people and a source of information for its decision-makers. The US Air Force's engagement with MAS and sister society MORS is testament to their dedication to and expertise in operations research. USAF is a perennial participant in MORS symposia where they frequently receive a tremendous number of accolades and awards.

The Department of Defense Supply Chain Operational Excellence Award was extended to the Air Force Global Logistics Support Center in 2010 and to the Sustainment Center in 2012. The Air Force Cost and Analysis Agency pioneered new and insightful risk and opportunity comparisons that provided a decision support tool used in the analysis of alternatives for our most complex satellite systems. This led to the 2015 David Packard Excellence in Acquisition Award won by the Space-Based Infrared System Geostationary Earth Orbit program that saved over $1 billion by use of these OR techniques in satellite purchase and modernization.

Analysts at the Air Force Headquarters have been awarded the MORS David Rist Award three times in the last six years in recognition of their superior contributions to national defense. The 2010 award cited creation and application of a tool which significantly broadened the scope and analysis supporting the Nuclear Posture Review and the follow-on Strategic Arms Reduction Treaty (START) negotiations with Russia. The 2014 award recognized a graphic model-based analysis of Air Force active duty and reserve component force size for every weapon system with regard to demands, costs, employment policies, and risk. The 2015 award was won for analysis that used a suite of purpose-built models and simulations (M&S) operating at multiple levels of resolution to inform a Presidentially-directed study on the employment of landmines and alternative systems in conventional tactical situations.

Military Operations Research Society • 2111 Wilson Boulevard, Suite 700 • Arlington, VA 22201
703-933-9070 • FAX 703-933-9066
morsoffice@mors.org
www.mors.org

We encourage the members of INFORMS to round out all these recognitions with this Prize in 2017. It would be an excellent way to punctuate the Air Force's place in the world of operations research!



Thomas Denesia
President
Military Operations Research Society

Chris Arney
President
Military Applications Society

Military Operations Research Society • 2111 Wilson Boulevard, Suite 700 • Arlington, VA 22201
703-933-9070 • FAX 703-933-9066
morsoffice@mors.org
www.mors.org

IDA | David S. C. Chu
President

October 26, 2016

Dr. Brian Denton
President-Elect, Institute for Operations Research
and Management Science (INFORMS)
5521 Research Park Drive, Suite 200
Catonsville, MD 21228 USA

Dear Professor Denton:

I welcome the opportunity to endorse the nomination of the United States Air Force for the 2017 INFORMS Prize.

It's been my privilege to observe the Air Force analytic community for over 40 years—as a RAND analyst, at the Congressionally Budget Office, in appointed positions in the Department of Defense, and now at the Institute for Defense Analyses. Perhaps more important, I've seen the value that the Air Force leadership places on good analysis—and on using good analysis with which to make critical decisions, decisions affecting the country's core interests.

In my view, that leadership stance explains why the Air Force analytic community has developed so well. It is a community dedicated to the pursuit of operations research as a deeply meaningful profession. A structured professional development system, nurtured by the Air Force over the past 75 years, continues to produce analysts who are both creative and operations-focused. This approach allows the Air Force to improve its own tools and methods, and to partner effectively with academic and industry experts. Better decisions are the natural result of such an enterprise.

You would send a wonderful signal of support to a key element of the profession by recognizing the Air Force's accomplishment, worthy of emulation by others. And you would encourage the next generation of analysts to devote their talents to some of the nation's most challenging problems. I urge you to award the 2017 INFORMS Prize to the United States Air Force.

Sincerely,

David S. C. Chu

Institute for Defense Analyses
4850 Mark Center Drive, Alexandria, Virginia 22311-1882 • 703.845.2300 • dchu@ida.org

MITRE

5 July 2016
J84A-L-8831

INFORMS
Brian Denton, President-Elect
5521 Research Park Drive
Suite 200
Catonsville, MD 21228

Dear Professor Denton:

I endorse with pleasure the nomination of the United States Air Force for the 2017 INFORMS Prize. As the Decision Analytics Group Leader at MITRE and as an INFORMS Fellow, I am in contact with Air Force programs and leaders. I am also a former judge for the ORSA Prize – the predecessor to the INFORMS prize.

The prevalence of and effectiveness of the Air Force analytics are evident throughout the enterprise.

The Air Force Academy was one of the three finalists for the 2016 INFORMS' UPS George D. Smith Prize for effective and innovative preparation of their students to be good practitioners of operations research. INFORMS also recognized the Warner Robbins Air Logistics Center with the 2006 Franz Edelman Award for using critical chain project management techniques to reduce the time required to repair and overhaul the C-5 transport aircraft by 33 percent. The Space-Based Infrared System Geostationary Earth Orbit program won the 2015 David Packard Excellence in Acquisition Award for saving over $1 billion by use of superior OR techniques in satellite purchase and modernization.

Awards like these confirm my observation that the Air Force employs superior operations research tools and methods throughout their decision-making process. The statistics offer further confirmation—a steady-state workforce of over 1050 career degreed operations research analysts, over 100 annual publications, 1262 Air Force Institute of Technology-trained masters-level OR graduates and an additional 63 doctorate-level OR graduates.

The Air Force commitment to universal employment of analytics is reflected in the world-class quality of their systems and their stewardship of resources.

The Air Force's engagement with Operations Research is longstanding and deep. In fact, it is older than INFORMS/ORSA with George Dantzig starting his original simplex method research while a Controller for the Air Force in 1947. The Air Force has generously funded Operation Research with $298m between 2006 and 2014 and its recipients include intellectual leaders such as Richard Bellman, Stuart Dreyfus, L. R. Ford and D. R. Fulkerson.

I am pleased to endorse the nomination of the US Air Force for the 2017 Informs Prize.

Sincerely,

Dr. L. Servi
Group Leader
Decision Analytics

LS/tj

The MITRE Corporation
202 Burlington Road
Bedford, MA 01730

University of Colorado at Boulder
Colorado LEEDS School of Business

419 UCB
Boulder, Colorado 80309-0419

July 6, 2016

Professor Brian Denton
2017 INFORMS President

Dear Professor Denton,

I have had the good fortune of working with many extraordinarily bright and creative US Air Force Operations Research professionals, mostly in their academic endeavors, over a span of nearly fifty years. It is with those interactions in mind that I enthusiastically recommend the US Air Force to receive the INFORMS Prize in 2017.

Optimization is both a tricky and vital part of planning at the strategic level, and the US Air Force is an organization dedicated to continual innovation and study of this field. I have witnessed first-hand many of their brightest OR analysts and scientists, and it is obvious from working with these individuals that the Air Force institutionally is dedicated to advancing the field of Operations Research, not only in practical applications, but also in the realm of innovative research at all levels and throughout all the OR disciplines. The Air Force Institute of Technology produces over 100 OR publication and 32 advanced-degree OR analysts annually. Analysts at the Air Force Headquarters have been awarded the Military Operations Research Society David Rist Prize three times in the last six years in recognition of their superior contributions to national defense.

From the great number of analysts the Air Force produces through its various academic institutions, to the emphasis they place on continuing education and experimentation among their current analysts, their dedication to this field and to elevating its practice to the highest level is unmatched.

In light of their continued outstanding contributions and support of the field of Operations Research, it is with great pleasure that I offer my support for the US Air Force to be honored with the 2017 INFORMS Prize.

Sincerely,

Fred Glover

Fred Glover
Distinguished Professor, Emeritus, University of Colorado System.
Chief Technology Officer, OptTek Systems, Inc.

U.S. Air Force Operations Research

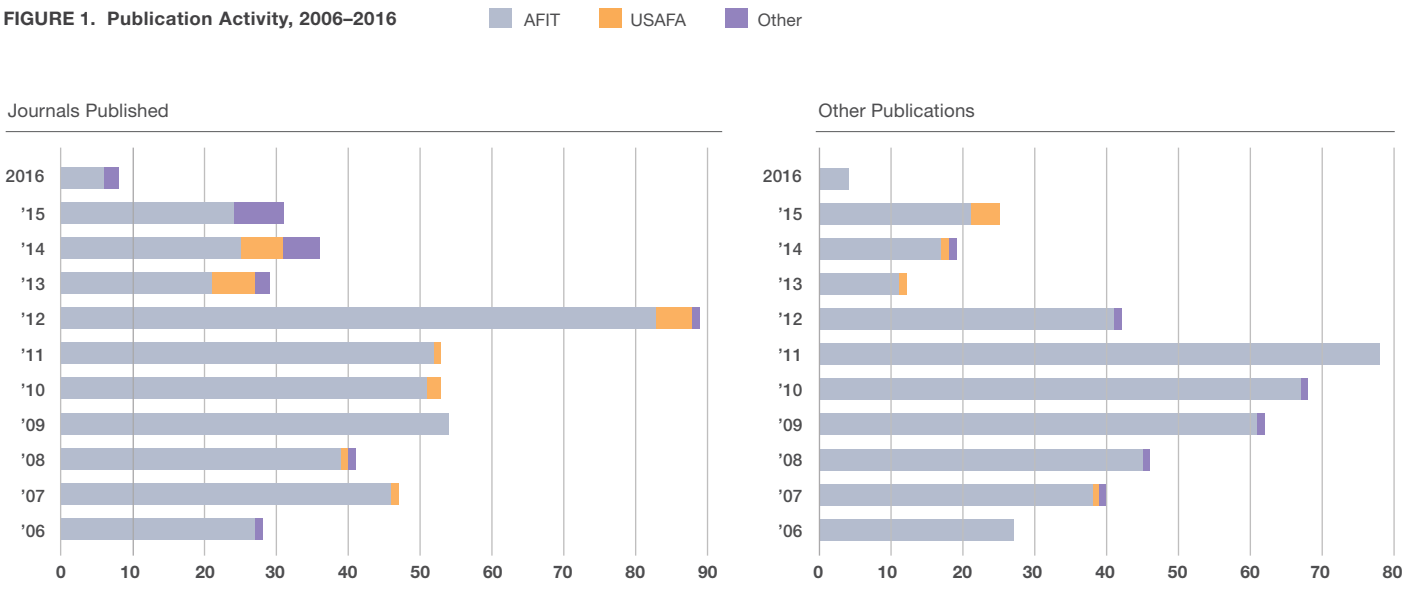
Education and Publications

O.R. HAS BEEN AND REMAINS AN INTEGRAL PART OF THE AIR FORCE'S RESEARCH EFFORT, starting with O.R.'s birth in World War II and continuing to this day. General Henry "Hap" Arnold, head of the Army Air Forces, established O.R. cells reporting to each major command and Numbered Air Force commanders in 1942. He formed the Army Air Forces Scientific Advisory Group. In November 1944, Theodore von Kármán chaired the group that continues to this day as the Air Force Scientific Advisory Board.

The Air Force's significant contributions to the fields of O.R. and management sciences are reflected by, among other aspects, the Air Force's numerous scientific and technical publications spanning multiple industries. This priority is made evident through the historical investment in Air Force academic institutions and organizations that support O.R. and management sciences research and publications.

Even before the Air Force was formally established as an independent service in September 1947, science and technology was at its core. On November 10, 1919, authorization was received to begin instruction at the Air School of Application. This school ultimately evolved into the graduate school Air Force Institute of Technology (AFIT). The focus on operationally relevant, high-quality research endeavors at AFIT has yielded almost 900 peer-reviewed journal or other articles (e.g., conference proceedings), spanning 263 different journals and more than 200 conference, symposia, and other professional meetings (see Figure 1). While the preponderance of articles is derived from research conducted at AFIT (with an average of 38 peer-reviewed and 37 other publications per year over the past ten years), a number of collaborative relationships with various elements of Air Staff, major commands, laboratories, and other academic institutions result from problems addressed. Since most AFIT students are officers with various Air Force experiences, many of them choose to investigate real-world problems during their degree programs. The subsequent relationships between AFIT and its former students contributes to a continued integration and application of O.R. to Air Force issues.

FIGURE 1. Publication Activity, 2006–2016



Since its inception, the Air Force has been a strong supporter of academic research. In 1948, the Air Materiel Command at Wright Field, Ohio, established the Office of Air Research (OAR) to be responsible for research. By October 1951, the Office of Scientific Research (OSR) was created as a staff office in Air Research and Development Command headquarters in Baltimore, Maryland. This office eventually became known as the Air Force Office of Scientific Research (AFOSR), which continues to fund basic research in mathematics, computer science, O.R., and management science. As a part of the Air Force Research Laboratory (AFRL), AFOSR's technical experts foster and fund research within AFRL, universities, and industry laboratories to ensure the transition of research results to support Air Force needs.[1,2]

AFOSR currently distributes its basic research program investment through 1,200 grants at more than 200 leading academic institutions worldwide, 100 industry-based contracts, and more than 250 internal AFRL research efforts.

With its staff of highly trained scientists and engineers, AFOSR manages the Air Force basic research program via three key partnerships:

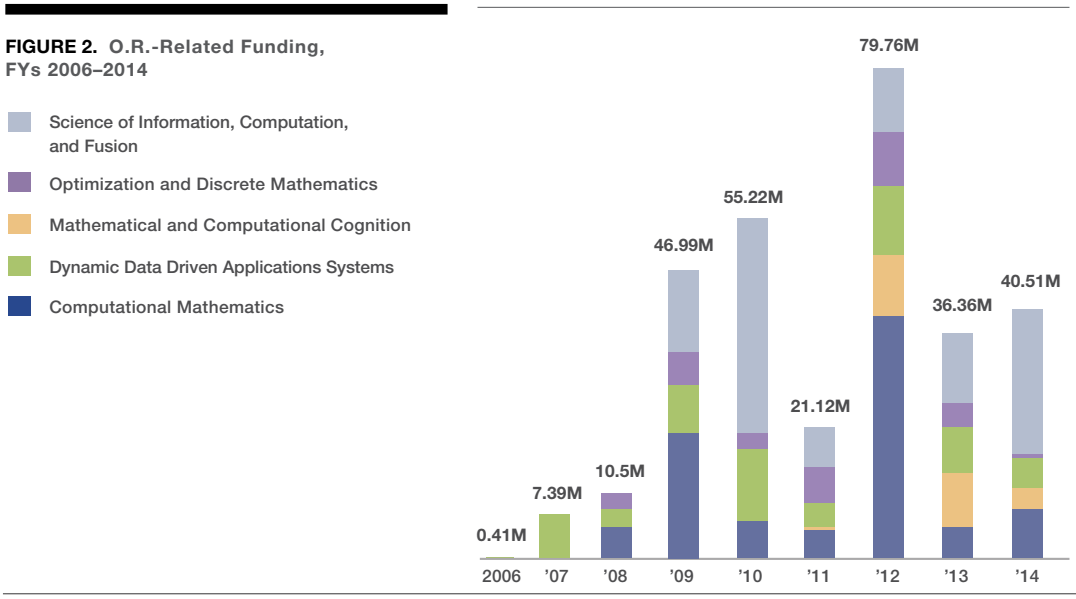
- **THE UNIVERSITY CONNECTION**
  Academia provides much of the backbone for our nation's technological progress while performing the bulk of the basic research. In addition to providing a prolific source of new knowledge and ideas, university research offers an exceptional training ground for developing and mentoring future scientists and advancing our national defense and economic security.

- **SMALL BUSINESS TECHNOLOGY TRANSFER (STTR) PROGRAM**
  The primary objective of the STTR program is to involve small businesses in Air Force–relevant defense research and to enable them to commercialize innovative technologies for the advancement of U.S. economic competitiveness. Specifically, the STTR program is designed to provide incentive for small companies, academic institutions, and nonprofit research institutions (including federally funded research and development centers) to transfer technical ideas from the laboratory to the marketplace.

- **AIR FORCE INTRAMURAL RESEARCH**
  AFOSR works closely with the other AFRL technical directorates to nurture and support quality research and, where advantageous, to integrate intramural and external research efforts to transition the latest basic research discoveries to follow-on levels in the research and development chain.

As seen in Figure 2, an average of $37 million per year (and an overall total of $298 million) from FYs 2007 to 2014 has been invested in various O.R.-related research areas. These efforts make up a

FIGURE 2. O.R.-Related Funding, FYs 2006–2014



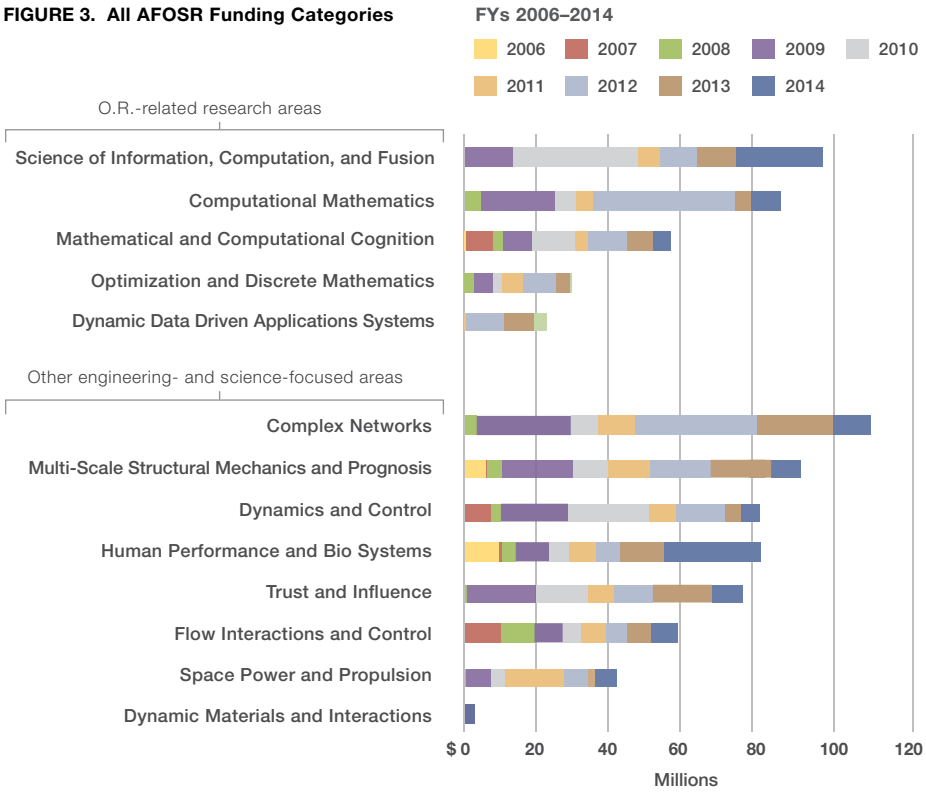
[1] Wright-Patterson Air Force Base, Air Force Office of Scientific Research, website: http://www.wpafb.af.mil/afrl/afosr.

[2] Air Force Office of Scientific Research History. "A Brief Organizational History" (July 17, 2016): http://www.wpafb.af.mil/Welcome/Fact-Sheets/Display/Article/842007.

subset of the over $850 million invested during the same period, in a number of engineering- and science-focused research areas that further contribute to Air Force O.R. (see Figure 3).

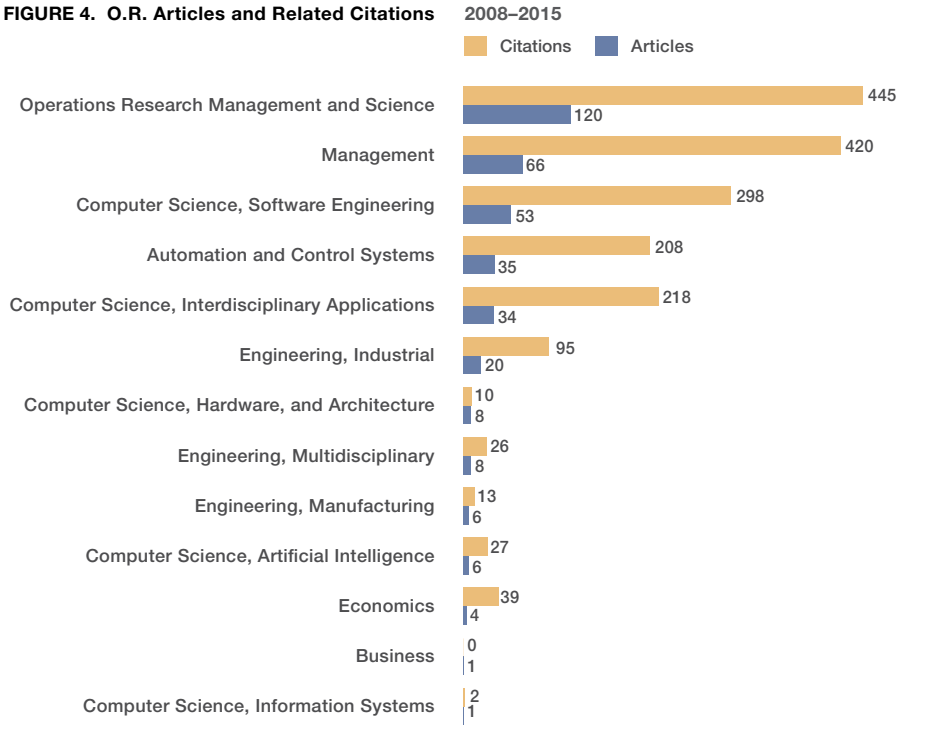
These investments have positively influenced the broader scientific and O.R. communities, as evidenced by the 1,497 articles published since 2008, 362 of which were specifically highlighted as classical O.R., or supporting O.R. endeavors. In addition, these works of research have generated widespread interest, been relied upon by other research areas and communities, and served as a testament to the quality of research and publications generated through the 1,800 citations of these Air Force–sponsored articles during the same period (see Figure 4).

FIGURE 3. All AFOSR Funding Categories



Although not included in the observations thus far, Air Force–sponsored O.R. activities conducted at federally funded research and development centers, such as RAND Project AIR FORCE and MITRE, are equally impactful. By partnering with these organizations, the Air Force has produced a number of early seminal works in the field of O.R. For example, RAND Project AIR FORCE alone has supported and sponsored Bellman and Dreyfus's work in dynamic programming, Dantzig and others' work in linear programming, and Ford and Fulkerson's network flow modeling, to name a few of the contributions to the field of O.R. These efforts continue today through RAND Project AIR FORCE.

FIGURE 4. O.R. Articles and Related Citations



U.S. Air Force Operations Research
Awards

OVER THE YEARS, THESE OUTSTANDING EFFORTS HAVE ALSO GARNERED RECOGNITION, dating back as early as the 1950s. In 1957, Clayton Thomas and Walter Deemer won the Lanchester Prize—the INFORMS award for the best contribution to O.R. and the management sciences published in the previous three years—for their work on "The Role of Operational Gaming in Operations Research" (*Operations Research*, Vol. 5: 1–27, February 1957).

This tradition continues today as noted in the following recent examples:

INFORMS Military Applications Society Koopman Prize Award

- **J.A. Jackson, G.S. Parnell, B.L. Jones, L.J. Lehmkuhl, H. Conley, and J. Andrew** won the INFORMS Military Applications Society Koopman Prize for the best paper in military operations research for their 1997 paper "Air Force 2025 Operational Analysis," *Military Operations Research*, Vol. 3, No. 4: 5–21. This study was in support of the Chief of Staff of the Air Force in considering future force structures and the science and technology needed to support them.

- **J. Todd Hamill, Richard F. Deckro, Robert F. Mills, and James W. Chrissis** also received this recognition in 2008 for their study "Reach-Based Assessment of Position," *Military Operations Research,* Vol. 13, No. 4: 59–78, which developed a new measure based on an actor's reachability to other individuals within a social network and posited an improved means to study adversarial, clandestine networks.

Pritsker Doctoral Dissertation Award

- **Lt Col J. D. Robbins,** Air Force, was the 2010 winner of the Pritsker Doctoral Dissertation Award, given by the Institute of Industrial and Systems Engineers (IIE) for the best dissertation in industrial engineering.

Bonder Scholarship for Applied O.R. in Military Applications

- **Dr. James Morris,** an O.R. analyst at the National Air and Space Intelligence Center, was the winner of a 2011 Bonder Scholarship for applied O.R. in military applications and a Defense Department full scholarship.

Military Operations Research Society David Rist Prize

Analysts at Air Force Headquarters have been awarded the Military Operations Research Society (MORS) David Rist Prize three times in the past six years in recognition of their superior contributions to national defense.

- **John Andrews, Patrick McKenna, and Karen Phipps** won the 2010 award for their work on the Nuclear Posture Review and the follow-on Strategic Arms Reduction Treaty negotiations with Russia. They created and applied a tool that significantly broadened the scope and analysis supporting our nuclear policy decisions.
- **Saiful Hannan** won the 2014 award for his analysis of Air Force active duty and reserve component force size for every weapon system with regard to demands, weapon system and manpower inventory, costs, employment policies, and risk. His graphical model has become an Air Force standard and is under consideration for Army implementation by the Center for Army Analysis.
- **Brian Rose** won the 2015 award for his analysis of the employment of land mines and alternative systems in conventional tactical situations. His suite of purpose-built models and simulations operating at multiple levels of resolution challenged a number of long-held operational assumptions and informed a presidential-ordered examination of the impact of land mines and possible alternatives.

MORS Clayton J. Thomas Award

The Military Operations Research Society's (MORS's) Thomas Award is named after one of the early Air Force analysts, Clayton J. Thomas, as a tribute to enduring value to the military O.R. community as to merit continuing, dignified recognition. Over the years, a number of analysts associated with the Air Force have been recipients of the Thomas Award, including the following MORS Fellows of the Society:

- 2015 – **Dr. Harry J. Thie, RAND Project AIR FORCE**
- 2013 – **Dr. Mark A. Gallagher, Lt Col, Retired, Air Force**
- 2011 – **Dr. Robert S. Sheldon, Lt Col, Retired, Air Force**
- 2009 – **Dr. Richard F. Deckro, Professor of O.R., AFIT**
- 2009 – **Mr. Patrick J. McKenna, Senior Analyst, U.S. Strategic Command**
- 2002 – **Dr. Gregory S. Parnell, Col, Retired, Air Force.**

MORS Fellow of the Society

The honor of MORS Fellow, which was created in 1989, recognizes those members that have had devoted significant, long-term contributions to MORS. Fellows are selected by the MORS Board of Directors and are elected for life. Twenty-two Air Force and Air Force–associated members are MORS Fellows. In addition, at least seven Air Force or RAND associates are INFORMS Fellows.

Air Force and RAND personnel have also been the recipients of a number of society awards and prizes, some of which are summarized in Table 1.

TABLE 1. INFORMS AND MORS AWARD RECOGNITION, 1957–2016

INFORMS	**35**
Community - AFIT - Outstanding Operations Research Educator	12
Community - DAS - DAS Practice Award	2
Community - DAS - Frank P. Ramsey Medal	1
Community - MAS - J. Steinhardt Prize	2
Community - MAS - Koopman Prize	2
Community - MAS - Outstanding Student Award	6
Community - MAS - Seth Bonder Scholarship for Applied Operations Research in Military Applications	2
Frederick W. Lanchester Prize	1
George B. Dantzig Dissertation Award	3
INFORMS Fellows	1
John von Neumann Theory Prize	1
Prize for the Teaching of the O.R./MS Practice	1
UPS George D. Smith Prize	1
MORS	**80**
Barchi Prize	4
Clayton J. Thomas Award	5
David Rist Prize	5
Dr. James T. Moore Graduate Research Prize	49
MOR Journal Award	3
Vance R. Wanner Memorial Award	14
Grand Total	**115**

U.S. Air Force

INFORMS Prize Committees

This 2017 INFORMS Prize nomination was compiled by a collection of committees shown below.

Core Commitee

ROLE	NAME	ORGANIZATIONAL POSITION
Chief Analyst	Mr. Kevin E. Williams	Director, Studies, Analyses and Assessments, Headquarters Air Force (AF/A9)
Lead	Dr. Mark A. Gallagher, Air Force Lt Col (Retired)	Technical Director, Studies, Analyses and Assessments, Headquarters Air Force (AF/A9)
Mentor	Dr. Ted Harshberger	Vice President and Director, RAND Project AIR FORCE
Deputy Lead	Dr. Iara C. Infosino	Chief, Resource Analysis Branch, Headquarters Air Force (AF/A9RP)
Member	Col John M. Andrew, Ph.D.	Permanent Professor and Head, Department of Mathematical Sciences, U.S. Air Force Academy
Member	Dr. Paul K. Davis	Senior Principal Researcher, RAND, and Professor, Pardee RAND Graduate School
Member	Dr. Lisa M. Harrington	Senior Operations Researcher, RAND Project AIR FORCE
Member	Dr. Jacqueline R. Henningsen	Former Director, Studies and Analyses, Assessments, and Lessons Learned, Headquarters Air Force (AF/A9)
Member	Dr. Muharrem Mane	Engineer, RAND Project AIR FORCE

O.R. Organization Subcommittee

ROLE	NAME	ORGANIZATIONAL POSITION
Lead	Ms. Patricia (Patti) Hickman	Deputy Chief Analyst of the Air Force and Deputy Director, Analysis, Assessments, and Development, Headquarters Air Force (AF/A9A)
Deputy Lead	Mr. David R. Pendergraft	Technical Advisor, Office of the Chief Analyst of the Air Force, Headquarters Air Force (AF/A9A)

Exemplar Topics Subcommittee

ROLE	NAME	ORGANIZATIONAL POSITION
Lead	Mr. David (Dave) L. Merrill	Director, Analyses, Assessments, and Lessons Learned, Headquarters Air Mobility Command (AMC/A9)
Mentor	Dr. Roy E. Rice, PE, Air Force Lt Col (Retired)	Chief Engineer, Teledyne Brown Engineering
Member	Mr. John G. Trifonovitch II	Director, Analyses, Assessments, and Lessons Learned, Headquarters Pacific Air Force (PACAF/A9)
Member	Mr. Richard A. Moore	Chief, Analyses, Assessments and Lessons Learned for Headquarters U.S. Air Forces in Europe and U.S. Air Forces Africa (HQ USAFE-AFAFRICA/A9)
Member	Colonel John C. Chong	Deputy Director, Analyses Foundations and Integration, Headquarters Air Force (AF/A9I)
Member	Mr. Douglas (Doug) E. Lee	Deputy Chief, Strategic Requirements, Integration and Analysis Division

Testimonial Subcommittee

ROLE	NAME	ORGANIZATIONAL POSITION
Lead	Dr. Gerald (Jerry) Diaz	Chief, Force Management and Enterprise Readiness Analysis Division, Headquarters Air Force (AF/A1PF)
Mentor	Dr. Gregory S. Parnell, Air Force Col (Retired)	Director, M.S. in Operations Management Program, Department of Industrial Engineering, University of Arkansas
Mentor	Dr. Thomas L. Allen, Air Force Col (Retired)	Former Director, Studies and Analyses Directorate, Joint Staff
Member	Lt Col Nicholas J. Zeisler	Senior Operations Research Analyst, Headquarters Air Force (AF/A9RP)

Publications and Awards Subcommittee

ROLE	NAME	ORGANIZATIONAL POSITION
Lead and Mentor	Dr. Richard F. Deckro	Professor, Air Force Institute of Technology (AFIT)
Deputy Lead	Col Jonathan Todd Hamill, Ph.D.	Chief Analyst of the U.S. Air Force and Director, Analysis, Assessments, and Development, Headquarters Air Force (AF/A9A)
Member	Maj Christina J. Obergfell	Chief, Cost Capability Analysis Branch, AFLCMC/XP-OZ/OSA
Member	Lt Col James D. Fielder, Ph.D. (Pigeon)	Division Chief, Analysis, Assessments, and Lessons Learned (A9Y), San Antonio, TX

History Subcommittee

ROLE	NAME	ORGANIZATIONAL POSITION
Lead and Mentor	Dr. Mark A. Gallagher, Air Force Lt Col (Retired)	Technical Director, Studies, Analyses and Assessments, Headquarters Air Force (AF/A9)
Deputy Lead	Dr. Donald Allen	Senior Operations Research Analyst, Headquarters Air Force (AF/A9F)
Mentor	Dr. Jim Bexfield	Military Operations Research Analyst, Institute for Defense Analyses (IDA)
Mentor	Dr. Robert S. Sheldon, Air Force Lt Col (Retired)	Senior Operations Research Analyst at Group W Inc, Washington, DC
Member	Mr. Michael Garrambone	Operations Research Analyst, Aerospace Systems Directorate, U.S. AFIT
Member	Mr. Jeffrey M. Saling	Chief, Mission Analyses Division, Headquarters Air Force (AF/A9FM)

Design and Review Subcommittee

ROLE	NAME	ORGANIZATIONAL POSITION
Lead	Dr. Robert A. Guffey	Lead Communications Analyst, RAND Project AIR FORCE
Deputy Lead	Mr. Richard Osburn	Command Information, SAF/PAI
Mentor	Dr. Ted Harshberger	Vice President and Director, RAND Project AIR FORCE
Designer	Ms. Yvonne Crane	Designer, RAND Corporation
Production Manager	Ms. Kimbria McCarty	Production Editor, RAND Corporation
Member	Ms. Sharon L. Thomas	Operations Research Analyst, Headquarters Air Force (AF/A9RI)

IMAGE CREDITS

Cover: U.S. Air Force/Senior Airman Dennis Sloan
Page 1: U.S. Air Force/Tech. Sgt. DeNoris Mickle
Page 5: U.S. Air Force/Bill Evans; U.S. Air Force
Page 6: NIST Archives; DIA/Abbie Rowe
Page 7: U.S. Army/Senior Airman Nicole Sikorski
Page 8: U.S. Air Force/Bobbie Garcia
Page 9: U.S. Air Force/Airman 1st Class Justin Veazie; U.S. Navy
Page 28: U.S. Air Force (AFOSR logo)
Page 30: INFORMS (Lanchester Prize Medallion)

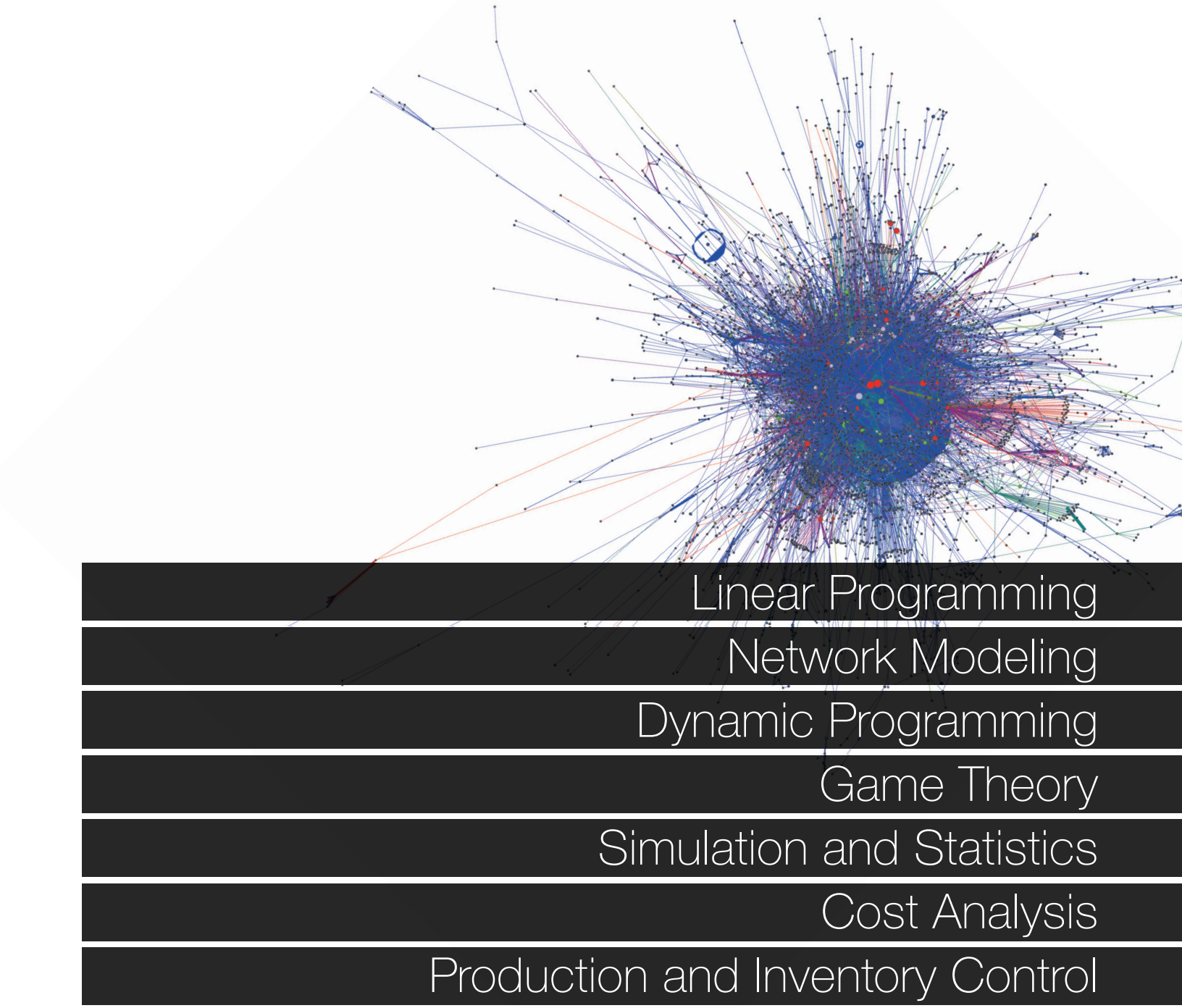
Nomination of the United States Air Force for the 2017 INFORMS Prize

Supplemental Material (Appendixes)

- **APPENDIX 1. U.S Air Force Contributions to the Foundations of Operations Research** 2
  - Linear Programming in Project SCOOP (Scientific Computation of Optimal Programs) 4
  - Network Modeling 6
  - Dynamic Programming 7
  - Game Theory 8
  - Simulation and Statistics 10
  - Cost Analysis 10
  - Production and Inventory Control 11
  - References 11
- **APPENDIX 2. Additional Exemplar Operations Research Topics in the U.S. Air Force** 12
  - Logistics and Infrastructure 13
  - Manpower Analysis 16
  - Operational Effectiveness 20
  - Acquisition of New Systems 24
  - Cost Analysis 27
- **APPENDIX 3. 75 Years of Operations Research in the U.S. Air Force (1942–2017)** 30
  - World War II and the Origins of Operations Research, 1940s 32
  - Institutionalizing O.R. Talent, 1950s 38
  - Force Structure Analysis and Vietnam, 1960s 41
  - The Cold War, 1970s–1980s 44
  - The Mideast Wars, 1990s–2005 48
  - The Mideast Wars and O.R. Reorganization, 2006–Present 50
  - Summary 52
  - References 52
- **APPENDIX 4. Organization of Operations Research in the U.S. Air Force** 53
  - The Air Force 54
  - Operations Research Analysts 54
  - Education for Operations Research 55
  - Air Force Organizational Alignment of Operations Research 56
  - Major Analytic Centers and Their Missions 57
  - RAND Project AIR FORCE 62
  - Air Force Management of Modeling and Simulations (M&S) and Studies 64
  - Summary 65

Appendix 1

U.S. Air Force Contributions to the Foundations of Operations Research



Linear Programming

Network Modeling

Dynamic Programming

Game Theory

Simulation and Statistics

Cost Analysis

Production and Inventory Control

Dating back to World War II and the Army Air Corps, operations research (O.R.) has been an integral element of the U.S. Air Force's approach to conducting its business of defending the nation and its national interests.

Pages 2–3 (image): Modeling visualization of a community network based on RAND Corporation social network analysis.

This tradition of organic analytic capability has been strengthened through the Air Force's close association with RAND, the other services, the National Laboratories, and a variety of agencies. This continued commitment to analysis is underscored by the establishment of individual Analyses, Assessments, and Lessons Learned Directorates, or "A9s," within each of the major commands in the Air Force.

Appendix 3: 75 Years of O.R. in the U.S. Air Force (1942–2017) outlines the birth and evolution of O.R. in the Air Force. Because of its importance to contributions to the foundations of O.R., we briefly describe RAND's origin and continued support to the Air Force.

Immediately following World War II, General Henry "Hap" Arnold took steps to preserve the research and development that had begun during the war by creating Project RAND—a contraction of "research and development." Project RAND was the first "think tank":

> Project RAND began in 1946 as a research project with a single client, the Army Air Forces. Initially the brainchild of engineer Frank Collbohm of Douglas Aircraft Company and Arnold's special consultant Edward Bowles, Project RAND was charged with investigating future weapons for the Army Air Forces. Arnold had research funding that he allocated to the project, and in March 1946 Project RAND came into official existence as a contract with the Douglas Aircraft Company to perform research on intercontinental warfare. . . . Project RAND started out by applying operations research to the much larger problem of intercontinental warfare. In the next year, Project RAND became the nonprofit RAND Corporation. (Johnson, 2002, p. 32)

While the RAND Corporation has evolved to be a multi-faceted research and consulting organization, its relationship with the Air Force has remained a constant for both the Air Force and RAND. The original Project RAND evolved into RAND Project AIR FORCE:

> . . . the only Air Force federally funded research and development center (FFRDC) concerned entirely with studies and analyses rather than systems engineering or scientific laboratories. (RAND website)

From its very beginning, this relationship resulted in a wide array of seminal O.R. studies. Johnson (2002) writes that RAND researchers have been progressively developing systems analysis methods in an attempt to create a "science of warfare" (p. 41).

In this appendix, we will focus on several seminal efforts in O.R. that originated with the U.S. Air Force and its partnerships with RAND. While by no sense a complete review, it illustrates key foundations of O.R. that are rooted in the U.S. Air Force support and involvement.

Linear Programming in Project SCOOP

(Scientific Computation of Optimal Programs)

BECAUSE LINEAR PROGRAMMING WAS THE FIRST KEY foundation of O.R. rooted in the U.S. Air Force, it is worth summarizing some history leading to the famous simplex method developed by George Dantzig. The same history is presented in Appendix 3 through different lenses.

(top) Interior of the UNIVAC I

Perhaps the most famous of the Air Force's support of O.R. is Project SCOOP, which began just before the creation of the U.S. Air Force as a separate service:

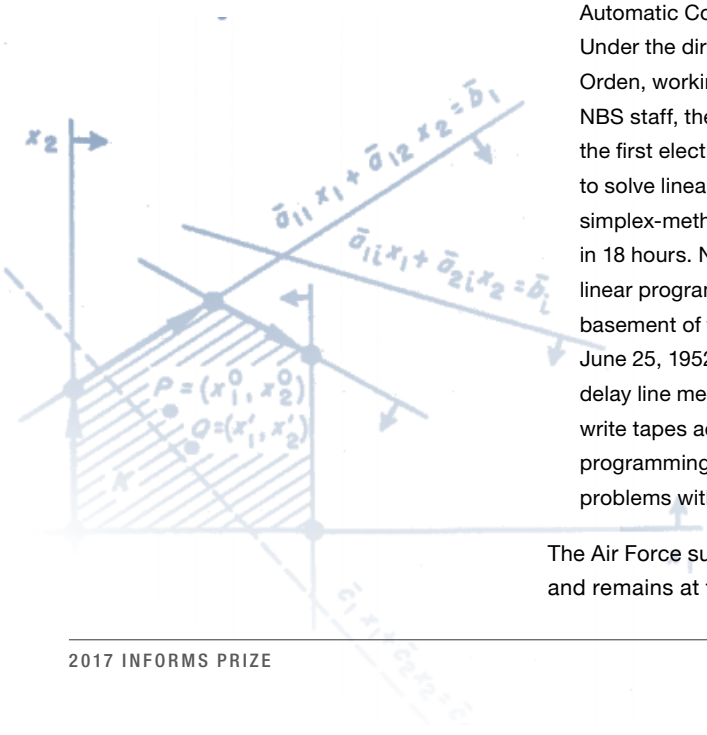
> In June 1947, a month before the National Security Act created the U.S. Air Force as a separate branch of the military, the Air Force established a major task force to work on its computationally challenging, large-scale planning processes. Later named Project SCOOP (Scientific Computation of Optimal Programs), the newly formed task force featured some of the brightest minds in the country, including George B. Dantzig, who served as chief mathematician. (Horner, 2007)

While working with Project SCOOP, Dr. Dantzig developed his work on the simplex method. One of the earliest reports on his approach was written for the U.S. Air Force Comptroller in 1948 and titled *Programming in a Linear Structure*:

SEAC, 1950

In 1948, the Air Force gave the National Bureau of Standards (NBS) $400,000 for the development of the SEAC (Standards Eastern Automatic Computer). . . . Under the direction of Alex Orden, working with the NBS staff, the SEAC was the first electronic computer to solve linear programming problems, e.g., in 1951, using the first stored-program simplex-method, a 48 equation by 71 variable Air Force deployment model was solved in 18 hours. NBS mathematicians, in particular Alan Hoffman, also worked on SCOOP linear programming issues. For SCOOP, the Air Force installed the second UNIVAC I in the basement of the Pentagon in Room BD944. It was officially accepted by the Air Force on June 25, 1952, and retired in 1958. The UNIVAC had a 1,000-word high-speed mercury delay line memory, accessed at ten-thousandths of a second, and eight magnetic read/write tapes accessed at 1,000 words per second. It was used to solve many Air Force linear programming deployment and scheduling problems. . . . The UNIVAC LP code could solve problems with 250 equations and 500 variables. (Horner, 2007)

The Air Force supported the initial development and implementation of linear programming and remains at the forefront of supporting computational methods and hardware.



Dr. George Dantzig

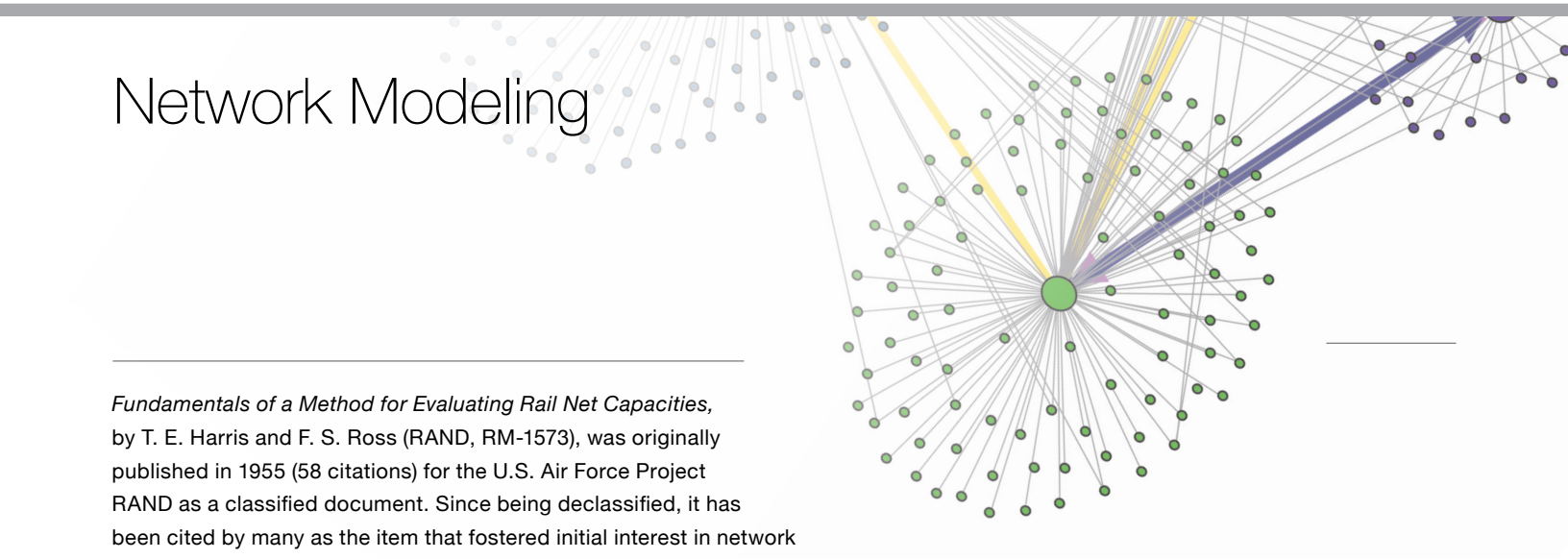
In 1952, Dr. Dantzig left Project SCOOP to join RAND, where he continued his work of optimization problems there and later at Berkeley and then Stanford (Hartwig and Johnson, 2012). Dr. Dantzig and his students and colleagues have had an immeasurable impact on the field of optimization and O.R. in general. While a review of all his works for the Air Force is beyond the scope of this appendix, Hartwig and Johnson (2012) provide a list of those works. To note a few, Dantzig's *Linear Programming and Extensions*, originally prepared for U.S. Air Force Project RAND (R-366-PR) in August 1963 and then published by Princeton University Press in 1963, has 9,101 citations in Google Scholar.

A review of the Defense Technical Information Center (DTIC) unclassified database for documents produced or sponsored by the Air Force with the phrase "linear programming" in the citation information (including title, abstract, and keywords) yields 414 results. Table 1 lists seminal linear programming publications from then or previous Air Force analysts.

TABLE 1. EXEMPLAR SEMINAL LINEAR PROGRAMMING PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
George Dantzig, *Linear Programming and Extensions*, RAND R-366-PR, Princeton, N.J.: Princeton University Press, 1963	9,101
George B. Dantzig, "Upper Bounds, Secondary Constraints, and Block Triangularity in Linear Programming," RAND P-576, *Econometrica*, 1955	186
J. T. Moore and J. F. Bard, "The Mixed Integer Linear Bilevel Programming Problem," *Operations Research*, 1990	238
J. F. Bard and J. T. Moore, "A Branch and Bound Algorithm for the Bilevel Programming Problem," *SIAM Journal on Scientific and Statistical Computing,* 1990	355

Network Modeling



Fundamentals of a Method for Evaluating Rail Net Capacities, by T. E. Harris and F. S. Ross (RAND, RM-1573), was originally published in 1955 (58 citations) for the U.S. Air Force Project RAND as a classified document. Since being declassified, it has been cited by many as the item that fostered initial interest in network modeling. Alexander W. Boldyreff, working for RAND, published a variation mentioning the work of Harris and Ross titled "Determination of the Maximal Steady State Flow of Traffic Through a Railroad Network" in the then-titled *Journal of the Operations Research Society of America* in 1955 (45 citations). Another key study to come out of the Air Force's partnership with RAND is L. R. Ford and D. R. Fulkerson's classic work, *Flows in Networks* (RAND, R-375-PR), which was prepared as a report for the U.S. Air Force Project RAND and released in August 1962. This work was also published by Princeton University Press in 1962. This text is considered to have set the foundation for the study of network flow problems. Google Scholar shows that the text has 6,676 citations.

Related to this classic work are such items as Ford and Fulkerson's "Maximal Flow Through a Network" (RAND, RM-1400), which was ultimately published in the *Canadian Journal of Mathematics* in 1956 under the same title. This article has 2,625 citations. Ford and Fulkerson followed this with "A Simple Algorithm for Finding Maximal Network Flows and an Application to the Hitchcock Problem," originally written as RAND Research Memorandum RM-1604 in 1955 (338 citations) and later published in in the *Canadian Journal of Mathematics* in 1957 (22 citations). Ford and Fulkerson's "Constructing Maximal Dynamic Flows from Static Flows" was published in *Operations Research* in 1958 and has garnered 435 citations in Google Scholar. Both authors, as a team and individually, went on to publish a vast array of works in network flows and optimization; we have highlighted only a few items here.

Network modeling remains a critical area of study for the Air Force—internally, in partnership with RAND, and through funding research at universities. This brief summary of some of the foundational work done in conjunction with the Air Force is just the tip of the iceberg. A more recent example is the article "Composite Variable Formulations for Express Shipment Service Network Design," by Andrew P. Armacost, Cynthia Barnhart, and Keith A. Ware, published in *Transportation Science* in 2002. This piece has 159 citations and resulted from then Captain, now Brigadier General, Armacost's 2000 dissertation at MIT.

Network models and modeling permeate the Air Force, from interdiction modeling, through mobility modeling, to design and control of communications systems, to cyber warfare and defense. The Air Force continues to support a broad array of research, development, and applications in this area. Table 2 lists some seminal networking publications from Air Force research.

TABLE 2. EXEMPLAR SEMINAL NETWORKING PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
T. E. Harris and F. S. Ross, *Fundamentals of a Method for Evaluating Rail Net Capacities*, RAND RM-1573, 1955	58
Alexander W. Boldyreff, "Determination of the Maximal Steady State Flow of Traffic Through a Railroad Network," RAND RM-1532 *Journal of the Operations Research Society of America*, 1955	45
L. R. Ford and D. R. Fulkerson, *Flows in Networks,* RAND R-375-PR, Princeton, N.J.: Princeton University Press, 1962	6,676
L. R. Ford and D. R. Fulkerson, "Maximal Flow Through a Network," RAND RM-1400, *Canadian Journal of Mathematics,* 1956	2,625
L. R. Ford and D. R. Fulkerson, "A Suggested Computation for Maximal Multi-Commodity Network Flows," RAND P-1114, *Management Science,* 1958	407
L. R. Ford and D. R. Fulkerson, "Constructing Maximal Dynamic Flows from Static Flows," RAND RM-1981, *Operations Research,* 1958	435
Andrew P. Armacost, Cynthia Barnhart, and Keith A. Ware, "Composite Variable Formulations for Express Shipment Service Network Design," *Transportation Science,* 2002	159

Dynamic Programming

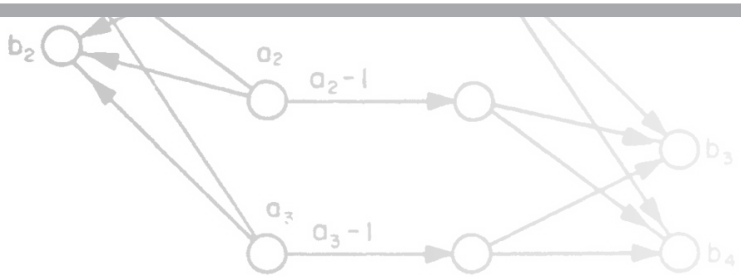
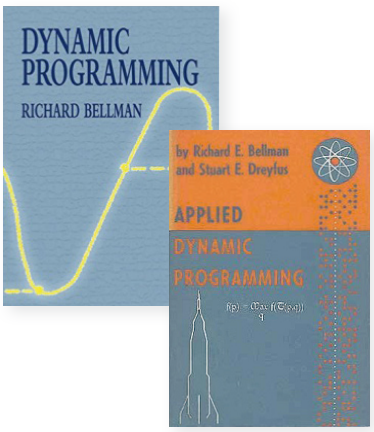


Fig. 12.1

$$f(p_1, p_2, \ldots, p_N) = \frac{t_k}{1 - q_k} + (1 - p_k) f \times \left(\frac{p_1}{1 - p_k}, \ldots, 0, \ldots, \frac{p_N}{1 - p_k} \right)$$

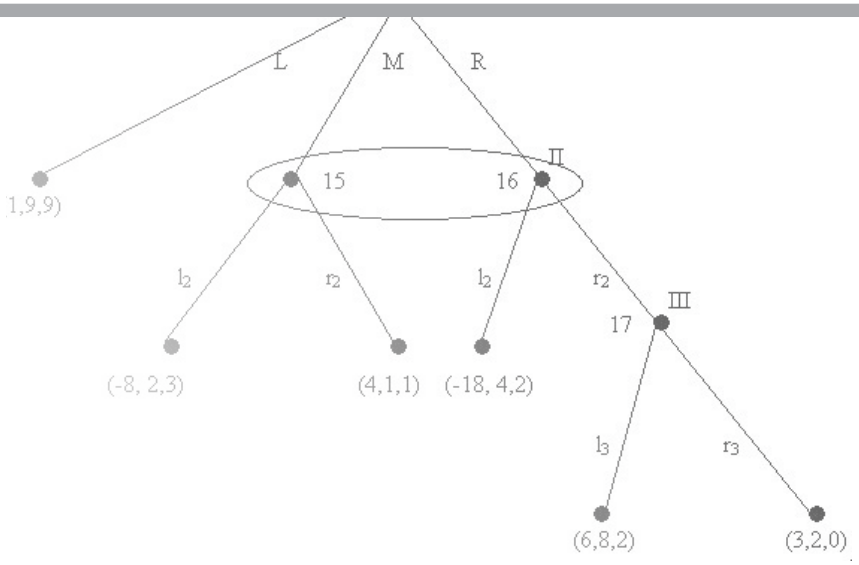


Richard Bellman's paper "On the Theory of Dynamic Programming," published in the 1952 *Proceedings of the National Academy of Sciences* (508 citations), was instrumental in setting the stage for the development of dynamic programming. Bellman's *An Introduction to the Theory of Dynamic Programming* (RAND, R-245), published in 1953, is also foundational to the field. In 1954, Bellman presented a paper titled "The Theory of Dynamic Programming" at the American Mathematical Society Meeting (515 citations), and in 1956 he published "Dynamic Programming and LaGrange Multipliers" in the *Proceedings of the National Academy of Sciences*. The latter article has a remarkable 18,070 citations, according to Google Scholar. Bellman and S. E. Dreyfus's 1962 U.S. Air Force Project RAND report *Applied Dynamic Programming* (R-352-PR) was also published by Princeton University Press, and Google Scholar indicates that it has 3,558 citations. Bellman and other scholars at RAND and elsewhere, with the support of the Air Force, have been instrumental in the creation and development of dynamic programming. A 1984 article in *IEEE Control Systems Magazine* titled "History and Development of Dynamic Programming," published in memorial to Professor Bellman, provides a brief history of dynamic programming and its impact (Bellman and Lee, 1984). Table 3 lists some of the seminal dynamic programing publications from Air Force–sponsored research.

TABLE 3. EXEMPLAR SEMINAL DYNAMIC PROGRAMMING PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
R. E. Bellman, "Dynamic Programming and LaGrange Multipliers," RAND P-869, *Proceedings of the National Academy of Sciences*, 1956	18,070
R. E. Bellman and S. E. Dreyfus, *Applied Dynamic Programming*, RAND R-352, Princeton, N.J.: Princeton University Press, 1962	3,558
R. E. Bellman, "The Theory of Dynamic Programming," July 30, 1954	515

Game Theory



Lloyd Shapley, who is credited with naming the book and film 'A Beautiful Mind,' indeed possessed one of his own. His contributions to game theory have and will continue to impact the field of economics for years to come.

— **Michael D. Rich**
President and CEO, RAND Corporation

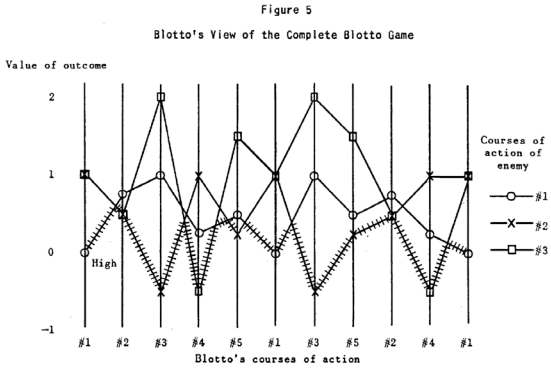
Melvin Dresher in the 1949 RAND report *Methods of Solutions in Game Theory* (P-103) provided one of the early works on the solution of game theory models. Leonard D. Berkovitz and Dresher over the years conducted a number of studies for the Air Force on game theory and air combat, including "A Game-Theory Analysis of Tactical Air War" (*Operations Research,* 1959, 63 citations), "A Multimove Infinite Game with Linear Payoff" (*Pacific Journal of Mathematics,* 1960, 12 citations) and "Allocation of Two Types of Aircraft in Tactical Air War: A Game-Theoretic Analysis" (*Operations Research, 1960,* 19 citations).

Lloyd S. Shapley, also of the RAND Corporation, is another prolific scholar in the area of game theory. Shapley's 1952 RAND study "A Value for n-Person Games," published in 1953 in *Contributions to the Theory of Games* (H. W. Kuhn and A. W. Tucker, eds.), has 6,312 citations. This work is the root of the well-known "Shapley Value" in game theory. Shapley went on to author a number of articles and books in the area of game theory, and his work continues to spur research by a number of scholars. Shapley won the 2012 Nobel Prize together with Alvin E. Roth for their research concerning stable allocations and the practice of market design. Shapley, a World War II veteran of the Army Air Corps who received the Bronze Star for his work in breaking a Soviet weather code, was also known for his work with the Shapley-Shubik power index, stochastic games, the Bondareva-Shapley theorem, the Shapley-Folkman lemma and theorem, the Gale-Shapley algorithm, the potential game concept, market games, authority distribution, multi-person utility, and non-atomic games, among other items.

Gaming in 1966. Players are (from left) Norton Kristie, General Ralph E. "Zip" Koon, Milton Weiner, and Admiral Bob Lockhart.

O. G. Haywood, Jr., in a 1954 article titled "Military Decision and Game Theory" in *Journal of the Operations Research Society of America,* developed his article from work from his Air War College studies (95 citations).

The Cold War era lead to an intensification of the military and strategic interests in game theory. Competition between the United States and the Soviet Union was frequently modeled with



From Haywood's "Military Decision and Game Theory" article.

game theory. The Air Force and RAND continue to have an intense interest in nuclear deterrence, arms races, and strategic conflict.

A good overview of the history of game theory can be found in the Stanford Encyclopedia of Philosophy at http://plato.stanford.edu/entries/game-theory/. Game theory continues to be used today, and RAND has a web page devoted to the topic http://www.rand.org/topics/game-theory.html. Game theory also has advanced deterrence, air defense modeling, counterterrorism, and other areas of interest to the Air Force. Table 4 lists some seminal game theory publications from Air Force–sponsored research.

TABLE 4. EXEMPLAR SEMINAL GAME THEORY PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
Melvin Dresher, *Methods of Solutions in Game Theory,* RAND P-103, 1949	
Leonard D. Berkovitz and Melvin Dresher, "A Game-Theory Analysis of Tactical Air War," RAND P-1592, *Operations Research,* 1959	63
Leonard D. Berkovitz and Melvin Dresher, "A Multimove Infinite Game with Linear Pay-off," RAND P-1151, *Pacific Journal of Mathematics,* 1960	12
Leonard D. Berkovitz and Melvin Dresher, "Allocation of Two Types of Aircraft in Tactical Air War: A Game-Theoretic Analysis," RAND P-1914, *Operations Research,* 1960	19
Lloyd S. Shapley, "A Value for n-Person Games," RAND P-295, in H. W. Kuhn and A. W. Tucker, eds., *Contributions to the Theory of Games* (AM-28), Princeton, N.J.: Princeton University Press, 1953	6,312
O. G. Haywood, Jr., "Military Decision and Game Theory," *Journal of the Operations Research Society of America,* 1954	95

This brief review is only a partial list of contributions to operations research by the Air Force and its partnership with RAND and through the Air Force Office of Scientific Research (AFOSR) and other agencies. Some further examples in other areas of operations research are presented in the tables that follow.

Simulation and Statistics

Some Air Force contributions to simulation and statistics are presented in Table 5.

TABLE 5. EXEMPLAR SIMULATION AND STATISTIC PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
Harry Max Markowitz, "Technical Appendix on the SIMSCRIPT Simulation Programming Language," RAND RM-93813, 1963	266
Philip J. Kiviat and A. Colker, "GASP—A General Activity Simulation Program," RAND P-2864, February 1964	38
Wassily Hoeffding, "The Strong Law of Large Numbers for U-Statistics," AFOSR Contract #AF 49(638)-261, 1961	196
Kenneth W. Bauer, Jr., and James R. Wilson, "Control-Variate Selection Criteria," *Naval Research Logistics,* 1993	32
Kenneth W. Bauer, Stephen G. Alsing, and Kelly A. Greene, "Feature Screening Using Signal-to-Noise Ratio," *Neurocomputing*, Vol. 42, Nos. 1–4, March 2000	81
Mark A. Gallagher, Kenneth W. Bauer, and Peter S. Maybeck, "Initial Data Truncation for Univariate Output of Discrete-Event Simulations Using the Kalman Filter," *Management Science,* 1996	17

Cost Analysis

Air Force–sponsored research contributed to cost analysis with examples shown in Table 6.

TABLE 6. EXEMPLAR COST ANALYSIS PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
Kenneth Arrow and Selma Arrow, "Methodology Problems in Airframe Cost-Performance Studies," RAND RM-456-PR, 1950	9
Armen Alchian, "Costs and Outputs," RAND P-1449, 1950	417
Armen Alchian, "Reliability of Progress Curves in Airframe Production," RAND RM-260-1, *Econometrica*, 1963	604
David Novick, "Use of Learning Curves," RAND P-267, 1951	5
David Novak, "Efficiency and Economy in Government Through New Budgeting and Accounting Procedures," RAND R-254, 1954	20
Gene H. Fisher, "Cost Considerations in Systems Analysis," RAND R-490-ASD, American Elsevier, 1971	35
Crocker and Reynolds, "The Efficiency of Incomplete Contracts: An Empirical Analysis of Air Force Engine Procurement," *The RAND Journal of Economics,* 1993	597

Production and Inventory Control

Table 7 shows Air Force advances in production and inventory control.

TABLE 7. EXEMPLAR PRODUCTION AND INVENTORY MANAGEMENT PUBLICATIONS

ARTICLE/STUDY/BOOK	CITATIONS
C. Sherbrooke, "Metric: A Multi-Echelon Technique for Recoverable Item Control," *Operations Research*, Vol. 16, No. 1, pp. 122–142, 1968	1,090
C. Sherbrooke, "VARI-METRIC: Improved Approximations for Multi-Indenture, Multi-Echelon Availability Models," *Operations Research,* Vol. 34, No. 2, pp. 311–319, 1986	259
J. Muckstadt, "A Model for a Multi-Item, Multi-Echelon, Multi-Indenture Inventory System," *Management Science,* Vol. 20, No. 4, pp. 472–481, 1973	422

The U.S. Air Force, with its partnership with RAND and its interaction with academia through AFOSR and the Air Force Research Laboratory, has been a foundational element to operations research since the early days of World War II. From the Air Force's beginning, General Arnold saw the value of O.R., and his successors have maintained it as an integral part of the U.S. Air Force and its mission.

REFERENCES

Bellman, R. E., and E. S. Lee, "History and Development of Dynamic Programming," *IEEE Control Systems Magazine,* Vol. 4, No. 4, November 1984, 24–28.

Ford, L. R., Jr., and D. R. Fulkerson, "A Simple Algorithm for Finding Maximal Network Flows and an Application to the Hitchcock Problem," RAND RM-1604 (1955), published in the *Canadian Journal of Mathematics,* 1957.

Ford, L. R., Jr., and D. R. Fulkerson, "Constructing Maximal Dynamic Flows from Static Flows," *Operations Research,* 1958.

Ford, L. R., Jr., and D. R. Fulkerson, *Flows in Networks,* R-375-PR, U.S. Air Force Project RAND, August 1962: http://www.rand.org/pubs/reports/R375.html

Ford, L. R., Jr., and D. R. Fulkerson, "Maximal Flow Through a Network," RAND RM-1400 (1954), published in the *Canadian Journal of Mathematics,* Vol. 8, 1956.

Hartwig, Daniel, and Jenny Johnson, *Guide to the George B. Dantzig Papers,* Stanford, Calif.: Stanford University Libraries, Department of Special Collections and University Archives, March 2012: http://www.oac.cdlib.org/findaid/ark:/13030/c8s75gwd/entire_text/

Horner, Peter, "Air Force Salutes Project SCOOP," *OR/MS Today,* December 2007: http://www.orms-today.org/orms-12-07/history.html

Johnson, Stephen B., *The United States Air Force and the Culture of Innovation 1945–1965,* Washington, D.C.: Air Force History and Museums Program, 2002.

RAND Corporation, "RAND Project AIR FORCE," no date: http://www.rand.org/paf/about.html

Appendix 2

Additional Exemplar Operations Research Topics in the U.S. Air Force

This summary provides 17 examples of operations research (OR) applications that have supported significant Air Force and Defense decisions within the last 10 years. We organize the topics in five areas.

No. 1 — Logistics and Infrastructure

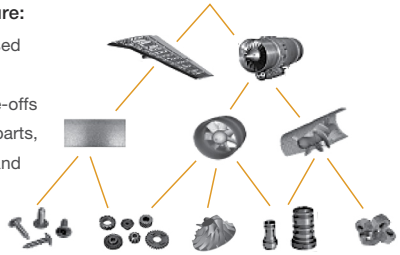
Managing the Air Force Supply Chain

Members of the 23rd Component Maintenance Squadron Propulsion Flight perform maintenance on a TF-34 engine.

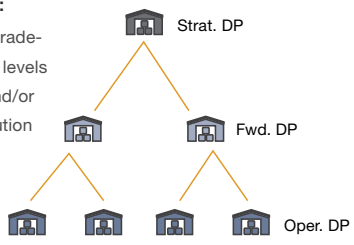
Air Force supply chain managers rely on advanced analytics to deliver affordable, world-class sustainment of weapon systems. For over a decade, the Air Force and RAND Project AIR FORCE have partnered to build supply chain modeling and forecasting tools to manage more than 100,000 repairable national stock numbers, valued at over $42 billion. Senior leaders rely on these analyses to make sustainment decisions for 36 major weapon systems, 27 engine lines, and dozens of other nuclear, space, cyber, and command-and-control systems. In addition, O.R. analysts are integrated throughout the entire supply chain management process, from strategic planning and budgeting to execution. Their analyses have influenced requirements for buying parts, repairing parts at depots, distributing parts to bases, establishing stock levels at bases, improving forecast accuracy, reducing inventory requirements, and strategically sourcing spares. This work has reduced the number of aircraft grounded due to lack of spare parts to its lowest level in Air Force history, while simultaneously saving $240 million in inventory costs. The Air Force's innovative use of O.R. for supply chain management has received numerous awards, culminating with the 2015 David Packard Excellence in Acquisition Award.

- The Air Force's innovative use of O.R. for supply chain management won the **2015 David Packard Excellence in Acquisition Award.**

Multi-indenture: Readiness-based sparing (RBS) assesses trade-offs within various parts, components, and sub-systems



Multi-echelon: RBS assesses trade-offs of stocking levels for individual and/or multiple distribution points (DP)



RBS minimizes the investment in inventory required to achieve readiness goals.

Planning Air Force Maintenance

U.S. taxpayers have enjoyed over $1 billion in first-year cost reductions and cost avoidance as a result of improved maintenance initiatives and sustainment efficiencies brought about by analytics. Lt Gen Bruce A. Litchfield, commander of the Air Force Sustainment Center at Air Force Materiel Command, published "The Air Force Sustainment Center Way," detailing how his organization applies analytic techniques, such as queueing theory, statistical analysis, and data visualization, to maintenance planning activities. Improvements based on these analytic-based insights enabled the organization to achieve world-class manufacturing strategies and practices that have garnered four Shingo Prizes for Excellence in Manufacturing since 2006. Air Force analysts embraced the stewardship responsibilities detailed in "The Air Force Sustainment Center Way" and saved hundreds of hours in aircraft depot flow time. This critical supply chain spans the entire maintenance process, from plans to budget to mission execution.

- Improvements based on the Air Force's O.R. analysis enabled world-class manufacturing strategies and practices that garnered four **Shingo Prizes for Excellence in Manufacturing** since 2006.

Supporting Base Realignment and Closure (BRAC) Commission

An F-35A Lightning II taxis down the 33rd Fighter Wing flightline after a sortie at Eglin Air Force Base, Fla. The Air Force F-35s make up the majority of the joint strike fighters located on base.

The Air Force and the Department of Defense are continually seeking ways to make operations and infrastructure more efficient while maintaining vital support to warfighters. O.R. plays a critical role in these efforts. In August 2001, Defense Secretary Donald Rumsfeld proposed a single round of base closures under his Efficient Facilities Initiative. After much debate, Congress eventually included a BRAC round to be conducted in 2005 as part of the National Defense Authorization Act for Fiscal Year 2002. This BRAC fully closed only a small number of installations (Army: 12, Navy: 5, Air Force: 5); the majority of final approved actions represented realignment and consolidation activities. The

- The Air Force Studies and Analysis Agency assisted with developing a linear program to maximize "military value" among the various basing options. This tool was used as a first step for Air Force deliberations in the BRAC process and identified an initial **$7.3 billion net present value savings** over the next 20 years.

Air Force Studies and Analysis Agency (AFSAA), now the AF/A9, supported the Air Force in determining the military value of all bases and assisted with developing a linear program to maximize "military value" among the various basing options. This tool was used as a first step for Air Force deliberations in the BRAC process and identified an initial $7.3 billion net present value savings over the next 20 years. AFSAA played a major role in developing the Air Force Force Structure Plan and the infrastructure necessary to support that plan, and then used that analysis to identify excess facilities and capacity. AFSAA also conducted an economic analysis of the effect of the closure or realignment of installations to reduce excess infrastructure. Additionally, the Office of Secretary of Defense (OSD) BRAC office sponsored the Cost of Base Realignment Actions (COBRA) model for all services to calculate costs, savings, and payback of proposed 2005 BRAC realignment and closure actions. AFSAA worked closely with the Air Force financial management, comptroller, and installations offices to ensure that model inputs were accurate, consistent, and in context with model design.

The Department of the Army recognized AFSAA and its team of four analysts (Lt Patrick S. Chapin, Capt Andrew J. Layman, Lt Col Donald E. Duckro, and Dr. James W. Harris) won the Dr. Wilbur B. Payne Memorial Award for Excellence in Analysis, Special Award, 2005. The team was commended for their unique and innovative applications of state-of-the-art operations research modeling, their analysis techniques and skills, and their dedicated service to provide rigorous, timely, and analytically supportable critical BRAC recommendations to the OSD Senior Leadership.

Further, AFSAA analyzed the resources required to increase the crew ratio (number of crews per aircraft) for Air Force future and legacy fighter and cargo aircraft. These in-depth analyses identified secondary and tertiary impacts of increasing crew ratios, such as triple maintenance shifts, additional base housing required, larger commissary, and greater hospital support. These insights further informed Air Force BRAC deliberations and formed the basis for Air Force's Future Total Force policy of combining guard units with active duty forces. These and other initiatives led the BRAC Commission to estimate the actual 20-year savings from this BRAC round to be approximately $15.1 billion.

- AFSAA analyzed the resources required to increase the crew ratio (number of crews per aircraft) for Air Force future and legacy fighter and cargo aircraft.
- Insights from this in-depth analysis, the Air Force's Future Total Force policy, and other initiatives led to an **estimated savings of $15.1B over 20 years** for this BRAC round.
- The Department of the Army recognized AFSAA and its team of four analysts won the **Dr. Wilbur B. Payne Memorial Award for Excellence in Analysis, Special Award**, 2005.

No. 2 — Manpower Analysis

Balancing Active and Reserve Manpower

Senior Master Sgt. Samuel Rock, an Air Force Reservist from Seymour Johnson Air Force Base, N.C., works with Senior Airman Quilan Johansen, of the 412th Aircraft Maintenance Squadron, on an F-16 Fighting Falcon. Reservists are augmenting F-16 support for KC-46 Pegasus testing at Edwards Air Force Base, Calif.

Manpower costs consume an increasing share of the Air Force budget. In recent years, this trend has fueled a contentious policy debate about the right mix of active duty, reserve, guard, and civilian manpower. These components have different employment status (full-time versus part-time), training requirements, missions, employment policies, and costs. The mix of components directly affects the Air Force's ability to conduct its missions and billions of dollars in annual budgets. To provide senior leaders with transparent, repeatable, and defendable tools for making force mix decisions, the Air Force built the Total Force Enterprise Analytic Framework. The framework balances Air Force active, guard, and reserve units to minimize cost while meeting mission demands and operational constraints across various scenarios. It also allows policymakers to examine the impact of different force sizes on specific job specialties. Of particular utility is an innovative graphical display that simplifies the evaluation and communication of component force mix options (see *Interfaces*, Vol. 45, No. 4, July–August 2015). These tools helped the Air Force leadership make force mix realignment decisions for the 2013 President's Budget and to justify them to Congress. The impact of the analytic framework has extended beyond the Air Force. In 2014, the congressionally directed National Commission on the Structure of the Air Force relied on the analytic framework, including outputs from the graphical display, in its report to Congress. The OSD, the Army, and the Institute for Defense Analysis have also adopted this analytic approach and presentation format. The Military Operations Research Society awarded the 2014 Rist Prize, its most distinguished technical award, to one of the Air Force project leaders in recognition of the work's innovation, its contribution to O.R., and its impact on major policy decisions.

- **The Total Force Enterprise Analytic Framework** balances Air Force active, guard, and reserve units to minimize cost while meeting mission demands and operational constraints across various scenarios.
- The Military Operations Research Society awarded the **2014 Rist Prize** to one of the Air Force project leaders in recognition of the work's innovation, contribution to O.R., and impact on major policy decisions.

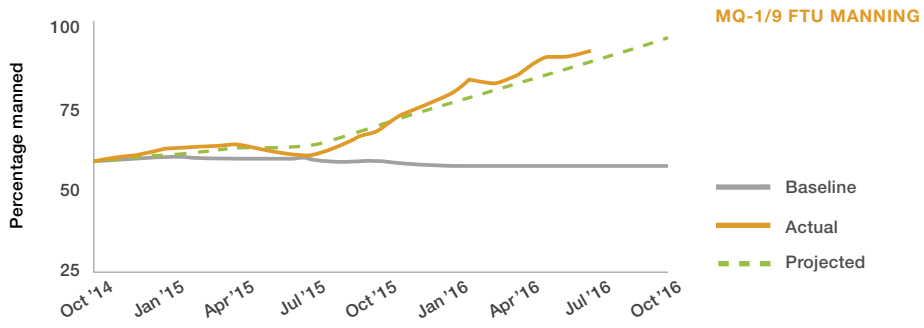
Meeting Remotely Piloted Aircraft Manning Challenges

An MQ-1B Predator sensor operator flies a remotely piloted aircraft training sortie in support of Red Flag 15-3 at Creech Air Force Base, Nev., July 23, 2015.

In the past decade, Air Force remotely piloted aircraft (RPAs) have provided 24-hour intelligence-gathering and rapid-response strike capability against terrorists and insurgents in remote parts of the world. These capabilities are an essential part of America's edge in counterinsurgency and other operations. While it was once hoped RPAs would *reduce* manpower requirements by removing pilots from the aircraft, they have actually *increased* the need for pilots and analysts to exploit the vast amount of collected intelligence. By 2015, the massive global demand for these capabilities led to a manpower shortage so dire that the Air Force could no longer carry out all the missions required by the Secretary of Defense. Addressing this problem required Air Force operations researchers to create a new manpower model that would reflect the unique characteristics of the RPA career field. The result was the RPA Manpower Model, a dynamic, Markovian personnel flow model that projects RPA manpower trends over time and evaluates the potential effects of proposed policy initiatives. Ultimately, the analysis showed that a combination of five major policy initiatives—temporarily decreasing the number of RPA missions, mobilizing the Air Force reserve component, increasing instructor pilot positions at the training unit, reducing staff positions, and expanding contractor support—would most efficiently and expeditiously improve manpower trends to meet the Secretary of Defense's goal of achieving a healthy RPA enterprise by October 2016. The analysis also specified the precise timeframe in which the Air Force should execute each initiative for maximum benefit. The Deputy Secretary of Defense approved these recommendations in April 2015 as part of a "get-well" plan that would affect more than 1,100 active duty Airmen operating the multibillion-dollar enterprise. As the Air Force implements the plan, it is employing the RPA Manpower Model to track manpower and to ensure that the RPA enterprise achieves appropriate milestones. The analytical insights gained from the RPA Manpower Model informed a comprehensive solution to an Air Force manpower shortage with significant combat implications. This work was accepted for publication in *Interfaces* under the title "Sustaining the Drone Enterprise."

- The analysis showed that a combination of five major policy initiatives—temporarily decreasing the number of RPA missions, mobilizing the Air Force reserve component, increasing instructor pilot positions at the training unit, reducing staff positions, and expanding contractor support—would most efficiently and expeditiously improve manpower trends.

An MQ-1 Predator and MQ-9 Reaper taxi to the runway in preparation for take-off on Creech Air Force Base, Nev., June 13, 2014. The aircraft are flown under the 432nd Wing, which trains pilots, sensor operators, and other remotely piloted aircraft crewmembers, and conducts combat surveillance and attack operations worldwide.



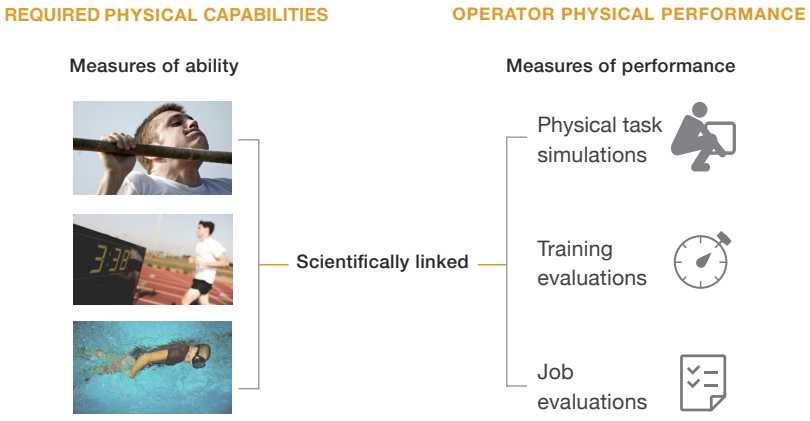
The get-well model projection of formal training unit (FTU) manning has proven accurate given real-world implementation of policy initiatives. The get-well model projects to meet the Deputy Secretary of Defense mandate of 100% manned by October 2016. The data are current as of July 2016.

Defining Gender-Neutral Physical Fitness Standards

In recent years, ground combat roles have opened to women throughout the U.S. armed forces. To implement this historic policy, the Secretary of Defense requested the Air Force and other services to reassess occupational standards, such as physical fitness, that are used to evaluate service members in specific roles. The Air Force organized a study team comprising exercise physiologists, O.R. analysts, and behavioral scientists from the Air Force Fitness Testing and Standards Unit in the Air Education and Training Command Studies and Analysis Squadron, and RAND Project AIR FORCE. The team conducted an in-depth, multi-year study to determine the physical requirements for all Air Force ground combat specialties and to produce a predictive physical fitness test that is occupationally specific, operationally relevant, and gender-neutral. The analysis used advanced O.R. methods, including correlation analysis, multiple regression, receiver operating characteristic curves, classification optimization, and decision analysis.

The resulting product was a list of critical tasks that was used to develop new physical fitness standards and tests covering approximately 4,300 positions within the Battlefield Airmen (BA) specialties. The critical physical tasks were submitted to the Secretary of Defense, and the new test standards are currently being implemented throughout the tactical air control party community. The importance of O.R. in this project cannot be overstated—it was essential to providing an objective, scientific basis for developing the Air Force's first-ever gender-neutral fitness standards predictive of combat performance and a foundation for the Secretary of Defense's historic decision to open all military combat positions to women.

> **We were extremely pleased with the work done in this area—it was essential for both our near-term efforts and decisions for the Women in Service Review—as well as providing us with opportunities to give our Airmen the best chance for battlefield success.**
>
> — **Brig Gen Brian T. Kelly**
> Director of Military Force Management Policy, Deputy Chief of Staff for Manpower, Personnel and Service, Headquarters U.S. Air Force



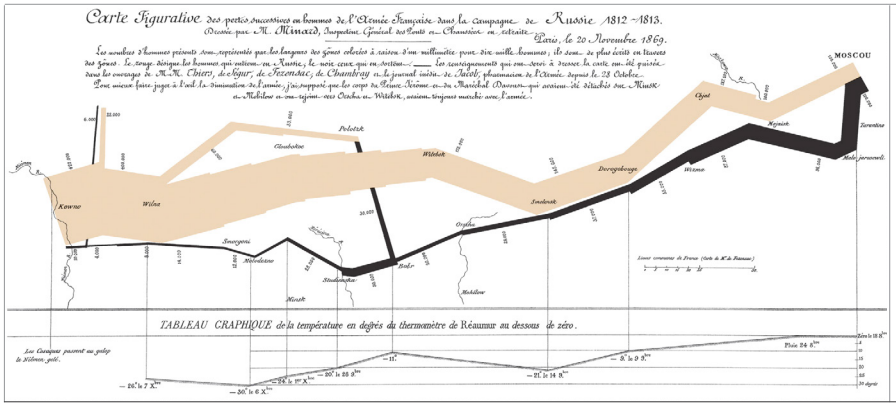
Operator physical performance can be measured in three primary ways: physical task simulations (PTSs), training evaluations, and on-the-job performance evaluations. These measures can help link operator performance (defined by occupationally specific job requirements, termed *critical physical tasks*) scientifically with the required physical abilities (e.g., strength, agility). RAND Project AIR FORCE helped design PTSs as part of the Air Force's ongoing effort to develop validated, gender-neutral occupational standards for Battlefield Airmen.

Visualizing Policy Effects on CV-22 Manning

Maj. Nick Noreus, 8th Special Operations Squadron CV-22 Osprey pilot, walks on the flightline at Hurlburt Field, Fla.

The tiltrotor CV-22 aircraft conducts long-range infiltration, exfiltration, and resupply missions for special operations forces. The CV-22 enterprise's operations and maintenance personnel experience is growing at a slower pace than planned and cannot generate the flight hours to support the programmed 74 crews. This phenomenon is a result of a significantly lower than anticipated utilization (UTE) rate. Simultaneously fielding the CV-22 in multiple locations while maintaining overseas combat operations has exacerbated this issue. Therefore, the Air Force Special Operations Command (AFSOC) must carefully manage its rated personnel pool to ensure adequate manning in the future. Air Force O.R. analysts used a queueing model to understand the complex factors that affect the rated personnel pool over time and to evaluate available policy options. While queuing theory is often applied to manpower analyses, it is not always presented in a way that enables policymakers to digest complex information and make an informed decision. Inspired by Charles Minard's famous graphic of Napoleon's March to Russia, the Air Force developed a graphic to communicate insights into CV-22 manpower. The graphic displays time (actual vs. programmed), the number of personnel in different positions, the number of billets and their locations, the relationships between different events, and policy options and assesses potential effects. The ability to visualize where personnel are in the system as well as the factors that influence their entrance, exit, and rates of progression through the system is a valuable tool for commanders. Using the Air Force's graphic, senior leaders in AFSOC were able to digest volumes of information, quickly change assumptions and parameters, and test the impact of their choices. As a result, several decisions were made, including limiting the CV-22's participation in exercises and visitor support operations, reducing the crew ratio, adjusting flying hours and making programmatic changes, making changes to the schoolhouse, pursuing multiple reliability improvement initiatives, extending intervals between inspections, and reevaluating basing timelines in the Pacific.

- The ability to visualize where personnel are in the system as well as the factors that influence their entrance, exit, and rates of progression through the system is a valuable tool for commanders.
- The Air Force's graphic tool resulted in several key decisions, including limiting the CV-22's participation in exercises and visitor support operations, reducing the crew ratio, and adjusting flying hours.



The Air Force CV-22 manpower graphic was inspired by Charles Minard's map of Napoleon's disastrous Russian campaign of 1812. The graphic is notable for its representation in two dimensions of six types of data: the number of Napoleon's troops; distance; temperature; the latitude and longitude; direction of travel; and location relative to specific dates.

No. 3 — Operational Effectiveness

Framing Warfighter Risk

The survival, evasion, resistance, and escape specialists are uniquely suited to analyze the operating environment to plan for evasion, captivity, and recovery considerations.

To effectively implement the National Security Strategy, Air Force leaders must continually balance investments in warfighting, operations, maintenance, and acquisitions across the air, space, and cyber domains. As defense budgets shrink, Air Force leaders face tough trade-offs about where to invest resources and where to accept more risk. Previously, leaders responsible for the Air Force's 12 core functions or basic mission sets (e.g., nuclear deterrence, air and space superiority, special operations, global mobility) would develop separate annual risk assessments that were subjective, often inconsistent with each other, and limited in scope. In 2010, the Air Force Chief of Staff challenged the analytic community to develop a consistent, systemically based, easily communicated framework for assessing risk within and across the Air Force major commands and core functions. Headquarters analysts developed a standardized technique for performing risk assessments in each mission area and a network assessment framework that highlights missions that drive risk across the enterprise, thus enabling senior leaders to prioritize limited funds for modernization and other investments.

The framework was adopted in 2012 for senior commander briefings to the Secretary of the Air Force and has been adapted for use by the Air Force Requirements Oversight Council and Air Force initiatives to support the Defense Department's planning, programming, budgeting, and execution process. The Marine Corps, Coast Guard, and Department of Homeland Security are currently considering adopting the framework for their own risk assessments. These efforts will allow the Air Force and other federal agencies to more effectively leverage fiscal resources that support our country's security.

Improving Integrated Air and Missile Defense in the Pacific

As the United States increases strategic focus in the Pacific region, a major concern has been exposing U.S. and allied forces to growing missile threats from potential adversaries. A strong integrated air and missile defense (IAMD) strategy must be based on the best basing postures, hardware (e.g., detection radars, missile defense batteries), and concepts of operation to defend U.S. and allied bases from attack. To meet this challenge, the Pacific Air Forces (PACAF) conducted or co-operated in a series of analytic events (e.g., Pacific Command Area Air Defense Commander's 2011 IAMD Summit, PACAF's 2013 Resilience Analysis Deep Dive, IAMD Wargames IV and V, and Cope Saki Mori wargames) to provide quantitative, substantiated, fact-based information on which to base new strategies and plans. These events leveraged a mix of analytic capabilities, including RAND's Combat Operations in Denied Environments analysis framework, which assesses combat operations during air base attacks. The new analyses directly informed Air Force, Department of Defense, and allied decisions regarding resource investments, operational plans, and coordination efforts among different countries. Synchronized, analytically rigorous approaches are essential to deterring adversary aggression in the Pacific region and ensuring that the United States and its allies can defend themselves if deterrence should fail. PACAF shared this methodology with O.R. analysts across the Air Force and Department of Defense, who identified this process as the standard to follow for similar analyses in other regional commands. PACAF also shared this method with the larger O.R. community at the 80th Military Operations Research Society Symposium, where it received the 2013 Barchi Prize.

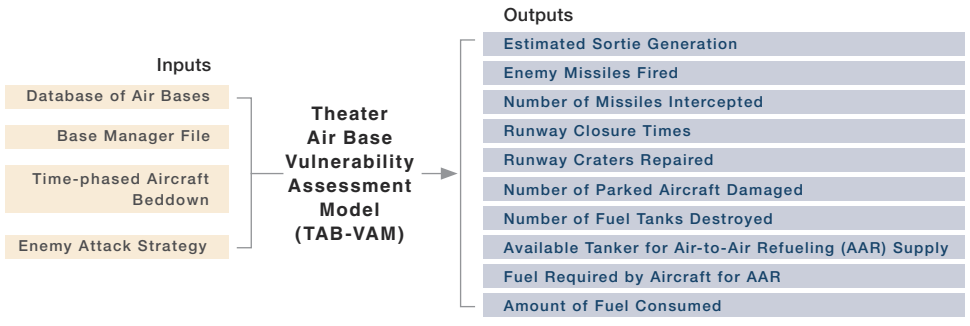
- The analyses from the assessment directly informed Air Force, Department of Defense, and allied decisions to help synchronize approaches to deter adversary aggression in the Pacific region.
- PACAF shared the new analyses and method with the larger O.R. community at the 80th Military Operations Research Society Symposium, where it received the **2013 Barchi Prize.**

Maintaining Combat Operations Under Air Base Attack

Airmen clear debris during airfield damage repair training at Andersen Air Force Base, Guam. Rapid runway repair can help a base sustain air operations while under attack.

The Air Force, the Office of the Secretary of Defense (OSD), and key allies are seeking cost-effective ways to increase operational resilience—the ability to withstand attacks on air bases and continue fighting. Since 2011, the Air Force and OSD have sponsored a series of analyses named "Combat Operations in Denied Environments" (CODE) conducted by RAND Project AIR FORCE. Analysts developed a suite of models that simulate the effects from various attack strategies on air base assets such as runways, parked aircraft, fuel infrastructure, maintenance facilities, and personnel; evaluate the cost-effectiveness of different mitigation options, including new technologies and alternative operating concepts; and identify cost-effective ways to position combat support resources within a region to enable resilient operations. The CODE methodology was constructed on the work of O.R. pioneers such as Harry Markowitz (who started at RAND in 1952) and Donald Emerson. The CODE methodology derives directly from the model Emerson developed and the analyses he performed addressing the same questions for the North Atlantic Treaty Organization (NATO) and Europe during the 1970s and 1980s. The CODE analysis shows how an optimized portfolio of cost-effective mitigation options can allow U.S. and allied air forces to maintain air operations against a spectrum of threats. This analysis underpinned an OSD decision to allocate $400 million for civil engineering, logistics, medical support, maintenance, missile defense, and other capabilities needed to support operational resilience in the Pacific region. These investments are relatively economical compared with the adversary capabilities they are intended to mitigate and with the valuable and vital air assets they protect. The analytic suite is recognized throughout the Air Force and joint communities as an innovative and relevant capability with potential applications across many functional areas. The analysis has already assisted in shaping key aspects of the Pacific Air Forces (PACAF) operational plans and will be extended to U.S. Air Forces in Europe in fiscal year 2017. The modeling suite has been widely shared and used in additional analytic efforts, such as Air Force Studies, Analysis, and Assessments' congressionally mandated tanker fleet analysis and PACAF's integrated air and missile defense and Cope Saki Mori wargames. CODE is aiding U.S. security interests around the world, reassuring allies of U.S. commitment, deterring adversary aggression, and ensuring that the United States and its allies can prevail in a conflict.

- The Air Force's CODE analysis shows how an optimized portfolio of cost-effective mitigation options can allow U.S. and allied air forces to maintain air operations against a spectrum of threats.



RAND developed TAB-VAM, a Monte Carlo simulation model, to analyze the complex trade-offs among basing strategies and threat mitigation options. Inputs reflect a given conflict scenario and aircraft beddown. Outputs quantify damage to air base assets and impact on theater-wide sortie generation.

Optimizing AC-130 Gunship Employment for Sustained Operations

A U.S. Air Force AC-130U "Spooky" gunship from the 4th Special Operations Squadron deploys self-protection flares over an area near Hurlburt Field, Fla., Aug. 20, 2008.

The AC-130 gunship—a heavily armed ground-attack aircraft variant of the C-130 Hercules transport plane—has protected special operations forces in combat since the 1960s. Battalion commanders sleep better when they hear the AC-130 droning on at night, knowing that the enemy will not venture out . . . a gunship has the watch. Air Force Special Operations Command (AFSOC) is in the process of acquiring a new fleet of 37 AC-130Js to replace its legacy AC-130U and AC-130W aircraft. Existing employment methods are influenced by demand, which notoriously is insatiable and outstrips supply. Therefore, AFSOC employs what is possible given a number of policy waivers, which stretch manpower and equipment beyond established limits.

This precarious situation is perpetuated by the proliferation of unconventional war and the shift in AFSOC's role to that of an enduring presence. As budgets contract in the presence of increasing demand, it is important to focus on managing resources efficiently with the long-term perspective in mind. To address this problem, O.R. analysts at AFSOC conducted a statistical analysis focusing on historical AC-130U and AC-130W operations and usage. The analysis is the cornerstone to right-sizing force package constructs. These constructs include determining the correct unit type code size and adjusting basing options so AFSOC can continue to sustain the current deployed counterterrorism capability; meet surge requirements should they arise; and be ready for the high-end fight, based on the availability of both manpower and equipment.

Staff Sgt. Olin Smith and Airman 1st Class Ryan Burtis—airmen assigned to the 27th Special Operations Maintenance Squadron AC-130 armament shop—transition a loading extension to transport inert munitions.

No. 4 — Acquisition of New Systems

Assessing Long-Range Strike

A B-2 Spirit flies to the North Pole Oct. 27, 2011, on a test mission from Edwards Air Force Base, Calif. B-2s bring unmatched long-range, precision-strike capability options to combatant commanders around the world.

The long-range strike (LRS) portfolio is a family of missiles; munitions; strike platforms; intelligence, surveillance, and reconnaissance systems; airborne electronic attack capabilities; and space-based communication assets. These systems collectively can attack the most heavily defended adversary targets. The United States must modernize this portfolio to meet evolving and future threats. Until 2010, with a lack of objective analysis to support the discussions, policymakers disagreed on which systems merited investment. To address this issue, the Deputy Secretary of Defense requested an objective assessment on the projected cost and capability associated with LRS options. Working with RAND Project AIR FORCE and Air Force analysts from multiple organizations, the Air Force Cost Analysis Agency (AFCAA) developed a complex model to analyze alternative portfolios employing multiple methods to estimate cost, ranging from parametric analysis to engineering build-up. O.R. analysts used regression analysis for futuristic systems based on technical data and historical cost information. These analysts also developed multi-variable equations that related technical and performance characteristics (e.g., weight and speed) to cost. These estimates were the basis of a complex model that determines the optimal portfolio, balancing cost and capability. The assessment resulted in an affordable acquisition strategy that could meet near- and long-term warfighter needs. The President approved the recommendations from this analysis and submitted those options to Congress. Today, the Department of Defense is pursuing the recommended acquisition strategy, which includes developing the new B-21 bomber. The LRS analysis is an exceptional example of how O.R. can build consensus within and across military services and federal agencies.

- The Air Force and RAND Project AIR FORCE assessment resulted in an affordable acquisition strategy for the long-range strike portfolio that could meet near- and long-term warfighter needs. The President approved the recommendations from this analysis and submitted those options to Congress.

Modeling Major Force Structure Decisions

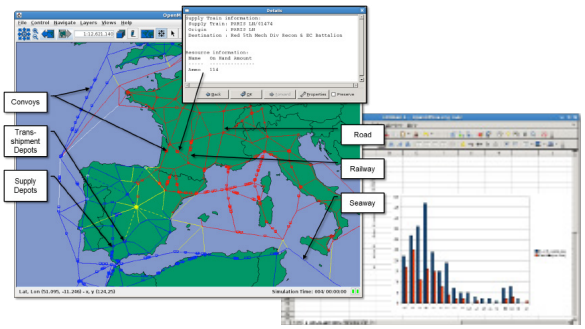
Air Force, Navy, and Marine Corp aircraft fly over carrier strike groups in the western Pacific Ocean. The Air Force relies on O.R. models to determine the mix of capabilities it will need to meet future security challenges.

Each year, the U.S. military services, the Department of Defense, Congress, and the President must assess the nation's force structure (i.e., mix of aircraft, ships, satellites, missiles, infantry battalions, and other equipment) required to support the National Security Strategy. These assessments directly inform allocation of the $585 billion defense budget and shape how the United States will pursue its national security objectives over the coming decades. Since 2009, the analytical backbone of these assessments—in the Air Force, the Navy, the Marine Corps, and the Joint Staff—has been the Air Force–developed Synthetic Theater Operations Research Model (STORM). STORM is a campaign-level simulation that models air, maritime, ground, and intelligence-surveillance-reconnaissance (ISR) forces in various conflict scenarios. STORM assists O.R. analysts in testing hypotheses involving large, complex warfighting campaigns with many dependencies and complementary and substitutable capabilities. The process is quick and inexpensive compared with live exercises. STORM provides a common framework for assessing capability options across the military services within the air, land, maritime, and ISR warfighting domains. Without tools like STORM, organizations would develop separate, inconsistent assessments that could obscure broad trade-offs essential to making cost-effective decisions at the national level. Analyses based on STORM are routinely presented to the secretaries of the military services, the Office of Secretary of Defense, and the Joint Staff, which in turn inform budget recommendations and decisions by the President and Congress.

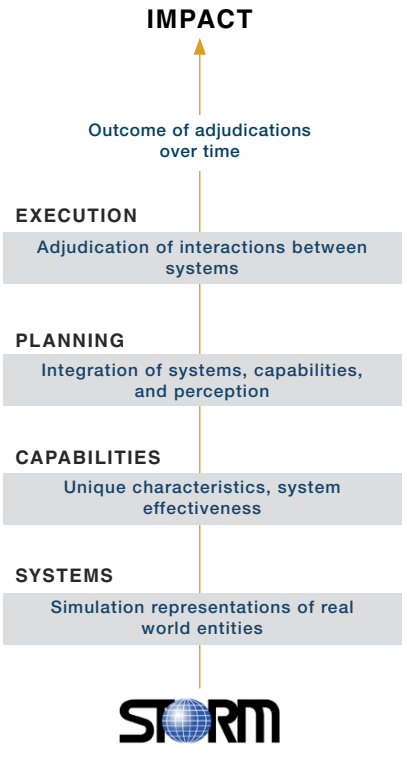
STORM continues to evolve, reflecting innovative work by the broader O.R. community. Graduate-level research has improved algorithms within STORM to better simulate real-world operations and to make the model more efficient. Several other defense-related models (e.g., Jaeger, AMOS, ALSWAT) leverage the technical underpinnings in STORM, saving a year of program development in each case. STORM has had a sustained effect on national policy decisions and the practice of O.R. within the defense community.

- STORM supports in-depth analysis of the campaign-level contributions of air and space power. It is designed as a multi-sided, stochastic computer simulation of military operations across the air, space, land, and maritime domain to examine issues involving the utility and effectiveness of air and space power in a theater-level, joint warfighting context.[1]

[1] David M. Pughes. *A Validation Assessment of the Storm Air-to-Air Prototype Algorithm*. (Thesis.) Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology (2000).



STORM campaign modeling enables a wide variety of users to trace contributions of individual weapon systems to joint warfighting campaign outcomes.



Analyzing Space System Alternatives

The Space-Based Infrared System geo-synchronous earth orbit (GEO)-2 satellite undergoes encapsulation.

As global reliance on satellite capabilities increases, so does the necessity to evolve aging space systems, which includes making existing systems more resilient to threats. Balancing these needs with the harsh realities of fiscal funding constraints creates a multi-dimensional optimization challenge for the Air Force. The Air Force has used O.R. techniques to address this problem for decades. Building on this work, the Office of the Secretary of Defense requested the Air Force Cost Analysis Agency to lead the cost portion on two analyses of alternatives (AoAs): the Protected Satellite Communications Services program and the Space-Based Infrared System Follow-On. The Air Force created several innovative models and tools for these analyses, including a model to optimize satellite size, weight, and power for a desired level of performance; a scheduling model that reflects known design and production challenges for satellite systems; state-of-the-art cost-estimating relationships; and a decision support tool to assist senior leaders with visualizing near- and long-term affordability associated with different options. The analyses focused on affordable acquisitions from the start and illuminated a credible, comprehensive, $70 billion trade space for these satellite programs. The same methods are now being used to generate the Air Force's annual Program Objective Memorandum, which supports the Department of Defense's planning, programming, budgeting, and execution process. Finally, the Air Force's leadership and technical immersion in these AoAs provided the platform to train future analysts, highlight effective processes, and share lessons learned.

- The Air Force's O.R. techniques assist senior leaders with visualizing near- and long-term affordability associated with different options. The analyses illuminated a credible, comprehensive, $70 billion trade space for these satellite programs.

The Advanced Extremely High Frequency system provides vastly improved global, survivable, protected communications capabilities for strategic command and tactical warfighters operating on ground, sea, and air platforms.

No. 4 — Cost Analysis

Reviewing "Should-Cost" Contractor Overhead

An HC/MC-130 Super Hercules aircraft is produced at the Lockheed Martin Aeronautics Company.

The Department of Defense's Better Buying Power initiative challenges the acquisition community to find ways to reduce costs throughout a defense program's life cycle. In 2011, the Air Force Cost Analysis Agency (AFCAA) led a "should-cost" review on overhead expenses for three major defense contractors. Using trend, correlation, regression, and statistical analyses, AFCAA found that companies historically underestimated their business direct labor base by up to 29 percent. AFCAA also derived estimating relationships to improve predictions for future overhead rates. Armed with this analysis and the typical adjustment factor for underestimation, the Defense Contract Management Agency (DCMA) was able to negotiate lower forward price rate agreements with several contractors, saving $1 billion over five years for Air Force acquisition programs such as the Joint Strike Fighter. AFCAA's analysis set the standard for future forward pricing rate agreement negotiations. DCMA incorporated these analysis techniques into its training program, with the goal of eventually applying those processes across all Department of Defense contractors. Contractors have also taken steps to improve their internal processes and data collection as a direct result of this analysis.

- Better Buying Power is the implementation of best practices to strengthen the Defense Department's buying power, improve industry productivity, and provide an affordable, value-added military capability to the warfighter.[1]
- AFCAA analysis armed the DCMA to negotiate lower forward price rate agreements with several contractors, **saving $1 billion over five years** for Air Force acquisition programs.

[1] http://bbp.dau.mil

Saving Lives with Efficient Fuel Transportation

A C-5M Galaxy aircraft.

During operations in Afghanistan, U.S. service members risked, and many lost, their lives moving military supplies by truck on roads vulnerable to insurgents. The Air Force sought to reduce this risk by moving portions of these supplies using cargo aircraft. An innovative technique developed by the Air Force made it possible for the first time to determine the economic feasibility of carrying extra fuel supplies on Air Force C-17 and C-5 cargo aircraft rather than on trucks. Analysts used 50 regression equations to normalize fuel-efficiency metrics for aircraft type, mission type, sortie length, cargo weight, and fuel on- or offloaded during flight. The analysis indicated that carrying extra fuel on cargo aircraft was feasible and more efficient than on ground transport.

This analysis convinced U.S. Transportation Command (USTRANSCOM) to adopt this practice. To date, 6,000 cargo aircraft sorties carried additional fuel into Afghanistan, removing 600 fuel convoys from the road and saving up to 25 lives (according to Army casualty estimates). USTRANSCOM estimates that this single research project saved the Department of Defense $270 million.

Since USTRANSCOM adopted the practice recommendations of the Air Force fuel transport analyses:

- **600 fuel convoys** have been removed from the road
- Up to **25 lives** have been saved
- Department of Defense has **saved ~$270M**
- **6,000 cargo aircraft sorties** have carried additional fuel into Afghanistan

Air Force Staff Sgts. Russell Johnson (right) and Stephen Adams watch as fuel barrels are airdropped from a U.S. Air Force C-17 Globemaster III cargo aircraft above Afghanistan.

Alleviating Strain on Special Operations Aircrews

Aircrew of an AC-130 gunship.

The proliferation of unconventional warfare operations (e.g., counterinsurgency, counterterrorism) in recent years has increasingly strained Air Force special operations personnel and their families, as well as the aircrew training pipeline. The Air Force sponsored two O.R. studies to alleviate this burden. The first analysis used an approach drawing on actual manning levels and historical flying hour data to determine optimal crew ratios (i.e., number of aircrews per operational aircraft) required to meet the Secretary of Defense's deploy-to-dwell policy (i.e., the amount of time personnel spend deployed versus home). This analysis resulted in Air Force Special Operations Command (AFSOC) increasing the crew ratios for the AC-130 gunship and C-146A transport aircraft, allowing personnel to return home on a normal rotation. The second study, performed by a doctoral student at the Pardee RAND Graduate School, developed an integer optimization model to inform decisionmakers about the respective effects on costs and readiness of existing and potential MC-130 aircrew continuation training policies. This study aims to cost-effectively meet the need for MC-130 trained and qualified crew members, a key special operations mission enabler. The study revealed that AFSOC could save a minimum of $1.3 million per year for each of the four existing MC-130 squadrons by shifting a portion of training from aircraft to simulators at existing squadron locations. These studies demonstrate how O.R. is helping the Air Force adapt to increasing real-world demands while containing costs and—most importantly—improving the quality of life for men and women who serve in these challenging roles. The MC-130 study, in particular, is just one example of how the Air Force fosters innovative work by tomorrow's O.R. professionals through its relationship with RAND and academic institutions.

- The O.R. studies resulted in AFSOC increasing the crew ratios for the AC-130 gunship and C-146A transport aircraft, allowing personnel to return home on a normal rotation.

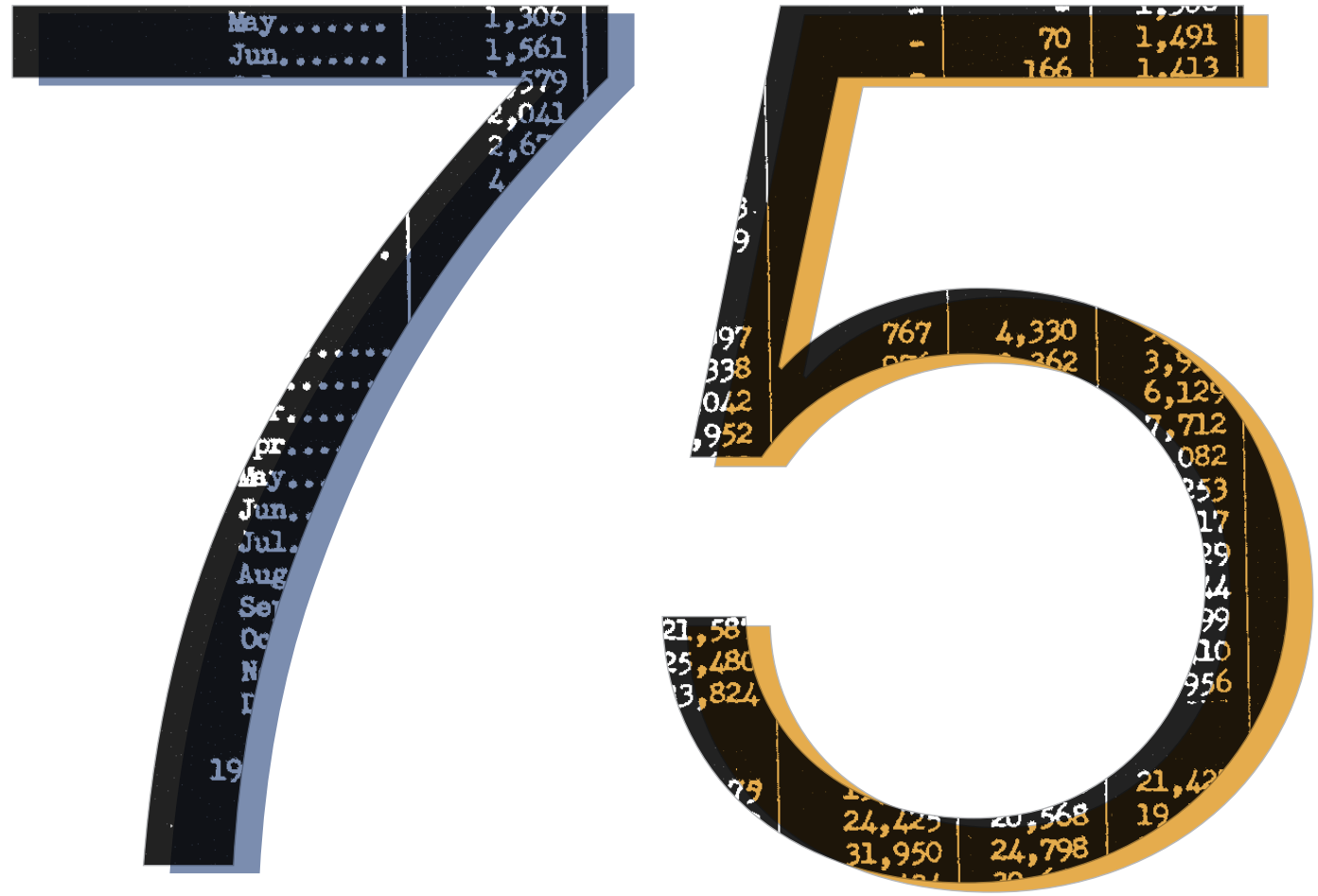
	Baseline	Temporary Duty	Multirole*	Simulator (Can 0.5)
Flight Hours (in plane)	1,024	1,008	964	740
Flying Hours Cost ($FY15)	$5.1M	$5.0M	$4.8M	$3.8M
Pounds of Fuel	6,022,000	5,822,607 (+trips)	5,675,340	4,343,607
Fuel Cost (at $3.7/gallon)	$3.3M	$3.2M (+trips)	$3.1M	$2.4M
Number of Sorties (in plane)	98	99	97	71
Savings (in terms of flying hours cost)	NA	$79,000 (+trips)	$298,000	$1.3M

Comparison of Savings Between Policies (One Squadron)

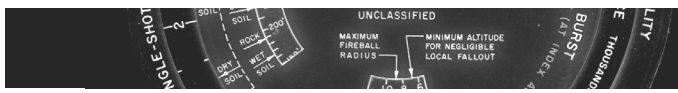
The analysis found that having a co-located flight simulator produces the most savings of all the policies, expending less fuel and pilot flying hours. Once the initial cost of the simulator has been covered by associated cost savings, the simulators will continue to generate savings.

* No low level

Appendix 3



Seventy-Five Years of Operations Research in the United States Air Force



Air Force leaders have integrated Operations Research (O.R.) into this Uniformed Service's culture from its initial existence in the 1940s to the present. From World War II bombing accuracy studies to Cold War attrition models and present-day force structure and risk-mitigation models, Air Force leaders have relied on sound O.R. counsel for their most important decisions. In this section, we trace some of the key events, organizations, and people responsible for weaving O.R. into the Air Force fabric.

1940s

WWII and the Origins of Operations Research

Air Force Operations Analysis (OA), as military O.R. was often termed early in the history of the Air Force, began in the U.S. Army Air Forces (USAAF) during World War II. The British Royal Air Force coined the term "operational research" during the early stages of that war as it worked to improve the application of fighters, radios, and radar to intercept the German bombers. USAAF quickly emulated their British allies. In the foreword of *Operations Analysis in World War II* (United States Army Air Forces, 1948), General Carl Spaatz, later the first Chief of Staff of the Air Force, describes his requesting and establishing the first

AF Operations Analysis
O.R. began in the U.S. Army Air Forces (USAAF).

Gen Carl Spaatz,
the first Chief of Staff of the U.S. Air Force, established the first O.R. section while he commanded the VIII Bomber Command.

Gen. "Hap" Arnold
U.S. Army Air Force Commanding General Henry "Hap" Arnold was an early advocate of O.R. in the USAAF and later the USAF.

USAAF World War II "Hap" Arnold Wings
The current symbol reflects this original design.

WWII
The outbreak of WWII

1939 **1942**

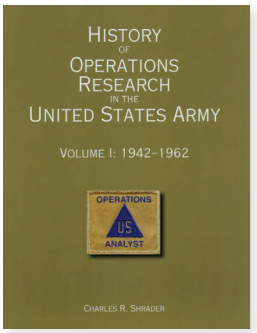
1940s

WWII and the Origins of Operations Research

O.R. section in 1942, while he commanded the VIII Bomber Command (soon thereafter redesignated the Eighth Air Force) at High Wycombe Airdrome, England. The successful work of this first section made other Army Air Forces commands aware of the OA concept and led to the establishment of the other OA sections.

Later in 1942, USAAF Commanding General Henry "Hap" Arnold championed the OA discipline and formalized it throughout the USAAF (Leach and Davidson, 1942). The headquarters for Operations Analysis in the USAAF was established as an Operations Analysis Division (OAD), aligned under the Chief of Management Control Division of the Air Staff.

The U.S. Army's *History of Operations Research in the United States Army, Volume I, 1942–1962* includes a section titled "The Origins of OR in the AAF." This section highlights how General Hap Arnold ordered the USAAF to study the experiences of the Royal Air Force (RAF) and the recommendations that the RAF had offered the USAAF. Working with the National Academy of Science and others, Colonel Gordon P. Saville and Cyril M. Jansky, Jr., obtained permission to set up an analyst group. On March 20, 1942, Jansky was appointed as a special consultant. Jansky established a small O.R. section to support USAAF air defense planning and operations at the staff level. While Saville and Jansky continued their work with operating units in late April or early May 1942, at Colonel Saville's direction Jansky wrote a "Memorandum on Operational Analysis in the War Department" outlining the inclusion of civilian analysts throughout the War Department. During the same period, Major Walter Barton Leach, USAAF, and Dr. Ward F. Davidson, director of research for Consolidated Edison, and their team made a comprehensive survey of O.R. activities in Britain and the U.S. armed forces and submitted their report on August 17, 1942. General Arnold turned the report over to his Advisory Council. Based on the report, the council's recommendations, and pressure from units to add operational analysis, Arnold noted to his commanders the value of integrating civilian experts and serving



USAAF Generals
"Hap" Arnold, Carl Spaatz, and Hoyt Vandenberg

1942

1940s

WWII and the Origins of Operations Research

officers to do operational analysis for the commands. General Arnold also directed that an Operations Analysis Division (OAD) be created in the Management Control Division of the Air Staff. OAD was established on December 31, 1942, with Leach as its chief. Leach, a USAAF officer, came to be considered by many as the "Father of U.S. Army Operations Research" (p. 163).

Table 1, which is from the *History of Operations Research in the United States Army, Volume I, 1942–1962*, shows the World War II operations analysis elements in the USAAF. Clearly, USAAF analysis was a worldwide endeavor during World War II.

TABLE 1.

Army Air Forces Operations Analysis Elements in World War II

Headquarters	*Station*	*Dates Active*	*Mission*	*Number of Personnel*[a]	*Chief of Section/Unit*	*Dates of Service as Chief*
Operations Analysis Division, HQ AAF	Washington, D.C.	Dec 42–Aug 45	Command	4	W. Barton Leach Roscoe C. Crawford (Acting)	Dec 42–Jul 45 Jul 45–Sep 45
Directorate of Air Defense, HQ AAF	Washington, D.C.	Mar 42–Sep 45	Air defense	8	Cyril M. Jansky, Jr.	Mar 42–Sep 45
I Bomber Command[b]	Long Island, N.Y.	Dec 41–Fall 43	Antisubmarine warfare	NA	Philip M. Morse[b]	Spring 42–Fall 43
Second Air Force	Colorado Springs, Colo.	Sep 43–Aug 45	Training	46	Deane W. Malott Joseph Kaplan Evan R. Collins	Sep 43–Dec 43 Dec 43–Jan 45 Jan 45–Aug 45
Third Air Force	Tampa, Fla.	Jul 44–Aug 45	Training	5	William M. Whyburn Will H. Connelly (Acting) Donald D. Durrell Will H. Connelly	Jul 44–Oct 44 Oct 44–Jan 45 Jan 45–Jun 45 Jun 45–Aug 45
Fourth Air Force	San Francisco,Calif.	Mar 44–Aug 45	Training	9	T. Stanley Warburton Anders J. Carlson	Mar 44–Jul 45 Jul 45–Aug 45
Continental Air Forces[c]	Washington, D.C.	May 45–Aug 45	Training	6	Lauriston S. Taylor	May 45–Aug 45
AAF Weather Wing	Ashville, N.C.	Jan 45–Aug 45	Weather	7	Joseph Kaplan	Jan 45–Aug 45
AAF School of Applied Tactics	Orlando, Fla.	Sep 42–Aug 45	Training	3	Robert L. Stearns David W. Raudenbush	Sep 43 Sep 43–May 45
Air Evaluation boards	Theater HQs	1944–1945	Evaluation	5	One operations analyst per board	NA
Strategic Bombing Survey	Europe, Pacific	1944–1945	Evaluation	1	Theodore Tannenwald, Jr.	Sep 44–Jan 45
AAF Training Aids Division	New York, N.Y.	Mar 44–Aug 45	Training	2	Arthur E. Pierce George P. Shettle	Mar 44–Apr 45 Jul 45–Sep 45
AAF Technical Training Command	Ft. Worth, Tex.	Jul 43–Sep 45	Training	1	Deane W. Malott	Jul 43–Sep 45
Eighth Air Force	England	Oct 42–Jun 45	Operational-bombardment	48	John M. Harlan Leslie H. Arps	Oct 42–Aug 44 Aug 44–Jun 45
VIII Fighter Command/VIII Air Support Command	England	Jun 43–Oct 44	Operational-fighter, training	7	Lauriston S. Taylor Ralph P. Johnson	Jun 43–Nov 43 Nov 43–Oct 44
Ninth Air Force	England, France, Belgium	Dec 43–May 45	Operational	21	Lauriston S. Taylor Carroll Zimmerman (IX Tactical Air Command)	Dec 43–May 45 Dec 43–May 45

Operations Analysis Division created

1942

1940s

WWII and the Origins of Operations Research

Over the course of World War II, a total of 245 analysts served in the OA program, with a peak strength of 175. These analysts were distributed over 26 OA sections, one with each of the 16 combat Numbered Air Forces plus several with other overseas USAAF headquarters and with USAAF training establishments in the continental United States. The largest of the OA sections was at the Eighth Air Force in England. Each Numbered Air Force had dedicated analysts on hand to propose and evaluate operational plans and the ensuing costs.

TABLE 1. CONTINUED

Army Air Forces Operations Analysis Elements in World War II

Fifteenth Air Force	Tunisia, Italy	Nov 43–May 45	Operational-bombardment	7	Samuel G. Frantz George W. Housner	Nov 43–Jul 44 Jul 44–May 45
Eleventh Air Force	Aleutian Islands	May 43–Jul 45	Operational	9	Sidney K. Wolf Hamilton M. Jeffers Clyde H. Bond Ralph W. Anderson	May 43–Sep 43 Sep 43 Oct 43–Aug 44 Aug 44–Jul 45
Fourteenth Air Force	China	Jul 44–Aug 45	Operational	8	Seymour J. Janow (Acting) George W. Taylor Carl J. Rees	Jul 44–Oct 44 Oct 44–Jul 45 Jul 45–Aug 45
AAF, Pacific Ocean Area (Seventh Air Force)	Hawaii, Guam, Okinawa	Aug 44–Aug 45	Operational	10	Douglas Shearer Kenneth Lambert Norman M. Newmark	Aug 44–Dec 44 Dec 44–Jan 45 Jan 45–Aug 45
Fifth Air Force	Australia	Feb 44–Jul 44	Operational	9	Sidney K. Wolf	Feb 44–Jul 44
Thirteenth Air Force	Southwest Pacific Area, Philippines	Oct 43–Jul 44	Operational	12	Robert L. Stearns Livingston Hall	Oct 43–May 44 May 44–Jul 44
Far East Air Forces[f]	Australia, New Guinea, Philippines	Jul 44–Aug 45	Operational	20	Sidney K. Wolf	Jul 44–Aug 45
AAF, India-Burma Theater (Tenth Air Force)	India	Jan 44–Aug 45	Operational	13	Fowler Hamilton LeRoy A. Brothers David Mayer	Jan 44–May 44 May 44–Sep 44 Sep 44–Aug 45
Twentieth Air Force (USASTAF Rear)	Washington, D.C.	May 44–Aug 45	Operational-long-range bombardment	26	Robert L. Stearns Livingston Hall	May 44–Jun 45 Jul 45–Aug 45
XX Bomber Command (Eighth Air Force, Pacific)	Kansas, India, China, Okinawa	Dec 43–Aug 45	Operational-long-range bombardment	11	Hamilton M. Jeffers Dan B. Dyer	Dec 43–Mar 45 Mar 45–Aug 45
XXI Bomber Command	Colorado Springs, Colo.; Guam	Oct 44–Aug 45	Operational-long-range bombardment	27	Donald H. Loughridge LeRoy A. Brothers	Oct 44–Apr 45 Apr 45–Aug 45
301st Fighter Wing, Very-Long-Range	Ie Shima	Jul 45–Aug 45	Operational-very-long-range escort	4	Theodore Tannenwald, Jr.	Jul 45–Aug 45

[a]The number of personnel shown represents total analysts and supervisors; it does not include clerical and support personnel. Not all people served at the same time. [b]Operations analysis support provided by Navy ASWORG. [c]Assumed control of numbered Air Forces in the continental United States in March 1945. [d]Separated into the Operations Analysis Section (OAS) for the Twelfth and Fifteenth Air Forces in October 1944. [e]Transferred to the Fifteenth Air Force in November 1943. [f]Absorbed OAS Fifth and Thirteenth Air Forces in July 1944.
NA = not available.
Source: Based on LeRoy A. Brothers and others, *Operations Analysis in World War II: United States Army Air Forces* (Philadelphia: Stephenson-Brothers, 1949).

1940s

WWII and the Origins of Operations Research

In his foreword to *Operations Analysis in the U.S. Army Eighth Air Force in World War II* (McArthur, 1990), former Operations Research Society of America president Hugh J. Miser notes:

> During the two and a half years of existence of the Eighth Air Force section, forty-eight persons with scientific and technical training were involved, representing more than a dozen specialties; mathematicians were the largest subgroup, with fifteen persons, thirteen of whom stayed with the section for six months or more. It should be noted that the mathematicians were functioning, not just in a mathematical role, but as scientists, developing theories about actual phenomena and applying them to problems of operations, policy, and plans.

Early OA combat contributions were pragmatic. Causal relationships could be derived from endpoint or forensic data, such as weapon effectiveness and target damage. As the OA personnel and their organizations matured, predictive analytics became a feature of their work, and much creativity was applied to integrate analytic insight into strategic planning and operational procedures. According to Brothers (1951), OA analysts were utilized to solve complex problems, such as target selection and bombing accuracy, defensive bomber formations, battle damage and aircraft loss, air base defense, fuel conservation, maintenance facilities and procedures, in-flight feeding, and comfort of crews.

Brothers (1954) gives an account of the well-known improvement in bombing accuracy that resulted from OA. In 1942, less than 15 percent of the bombs dropped fell within 1,000 feet of the aiming point. One commanding general had asked, "How can I put twice as many bombs on my targets?" OA analysts recommended three changes to address this goal: (1) the nearly simultaneous release of their bombs by all the bombardiers (instead of the practice of each bombardier aiming and releasing his own bombs), (2) each bomber salvoing its bombs instead of presetting them to release in a string, and (3) the decrease in the number of aircraft per formation from 18–36 to 12–14. As a result of these measures, the proportion of bombs that fell within 1,000 feet of the aiming point improved to 60 percent within two years.

> **...the mathematicians were functioning, not just in a mathematical role, but as scientists, developing theories about actual phenomena and applying them to problems of operations, policy, and plans.**
>
> — **Hugh J. Miser**
> Former President, Operations Research Society of America

Bombing Accuracy
As a result of OA analysis, the proportion of bombs that fell within 1,000 feet of the aiming point improved from 15 percent to 60 percent.

Eighth Air Force
An Army Air Force B-17 during raid of October 9, 1943, on the Focke-Wulf aircraft factory at Marienburg, Germany.

1942 **1943**

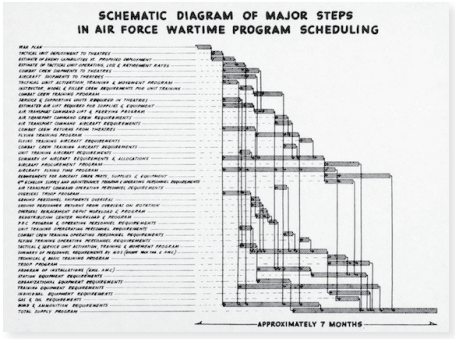
1940s

WWII and the Origins of Operations Research

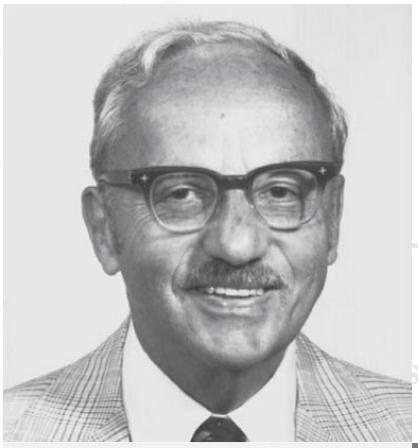
UNIVAC I
(top) Project SCOOP installed the first Pentagon computer to solve Air Force problems.

The beneficial results of OA were not limited to the European theater during World War II. W. J. Youden, a mathematician in the Eighth Air Force operations analysis section, had been instrumental in the improved bombing performance in 1942 and 1943. In 1944, he transferred to the Twentieth Air Force, where he contributed to the success of the B-29 operations in the Pacific theater (Miser, 1992).

The War Department was also developing OA applications in the USAAF's Combat Analysis Branch of Statistical Control. George B. Dantzig developed a reporting system that enabled combat units to record the number of sorties flown, aircraft lost and damaged, bombs dropped, and targets attacked, and he developed concepts for planning interrelated activities—ideas that would later help him structure resource decisions into a linear programming model. The War Department awarded him the Exceptional Civilian Service Medal for his accomplishments during World War II. After the war, Dantzig was chief mathematician for Project SCOOP (Scientific Computation of Optimal Programs), a major task force set up by the Air Force in 1947 to work on the high-speed computation of the Air Force planning process, under the direction of the economist Marshall K. Wood. Project SCOOP constructed and operated the 1950 National Bureau of Standards Eastern Automatic Computer (SEAC) and in 1951 installed the first Pentagon computer, a UNIVAC I, to solve Air Force problems. The SCOOP civilian staff of mathematicians, statisticians, and computational experts was responsible for formulating and solving a wide range of Air Force planning and programming problems. Within Project SCOOP, Dr. Dantzig developed the simplex method to solve linear programing problems, which Dongarra and Sullivan (2000) include as one of the top ten algorithms developed in the 20th century. The Project SCOOP staff collaborated with academic researchers, who helped bring the application of linear programing to industry and business (Gass, 2002).



Project SCOOP wartime diagram.



George B. Dantzig

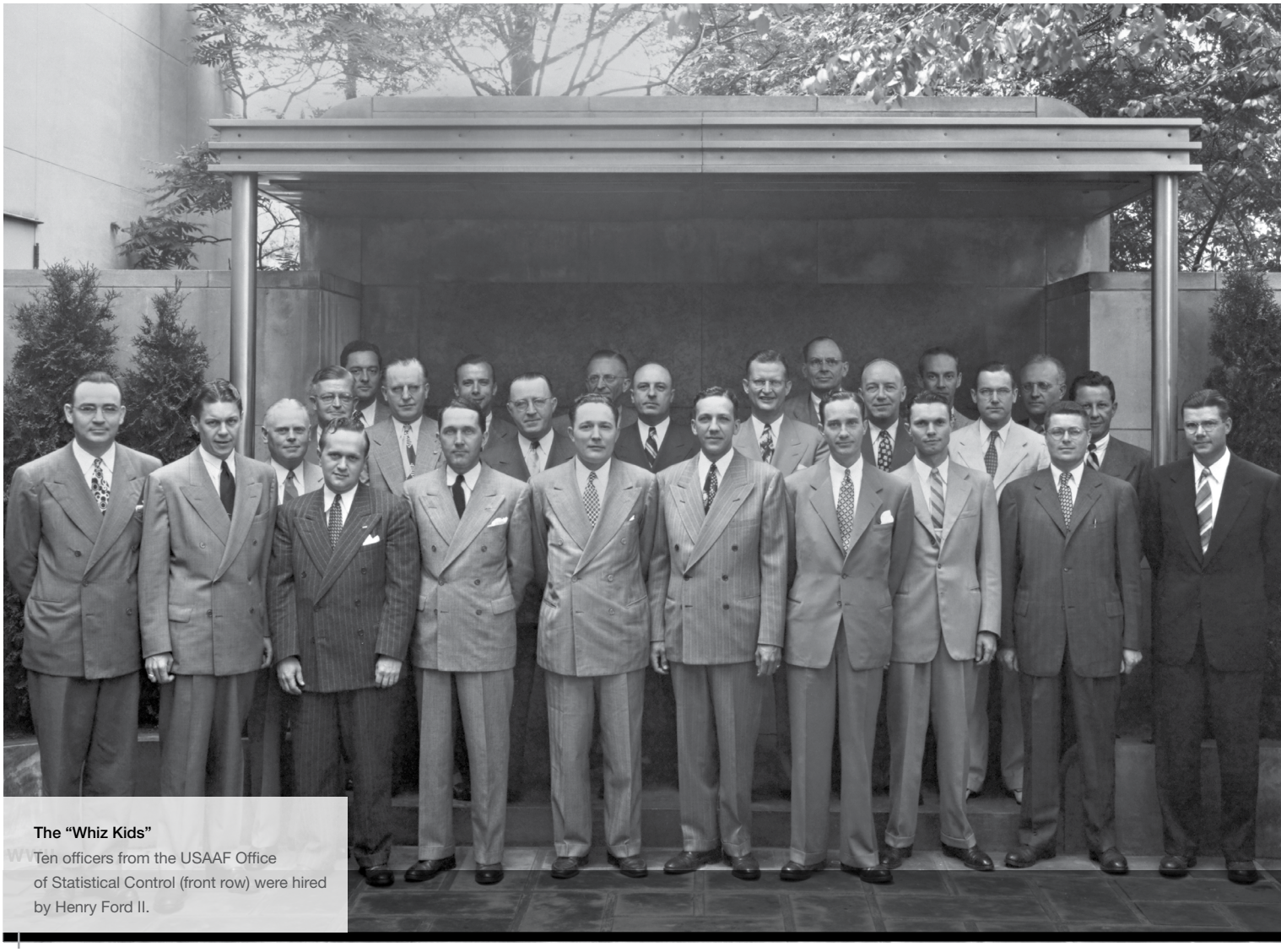
WWII ends

1942 **1945** **1950**

1950s

Institutionalizing O.R. Talent in the 1950s

With the war's end, most of the analysts returned to universities, laboratories, or other civilian pursuits. Brothers (1951) reports that by January 1946 only a dozen were left, about half of whom were finishing final reports. Among the many analysts returning to the private sector in 1946 was an enterprising group of ten officers from the USAAF Office of Statistical Control awaiting discharge at Wright Field in Dayton, Ohio. Led by Colonel Charles "Tex" Thornton and Lieutenant Colonel Robert McNamara, they convinced Henry Ford II to hire them all to help return his company to profitability. They came to be known as the Ford "Whiz Kids," of whom two became Ford presidents and five became Ford vice presidents.



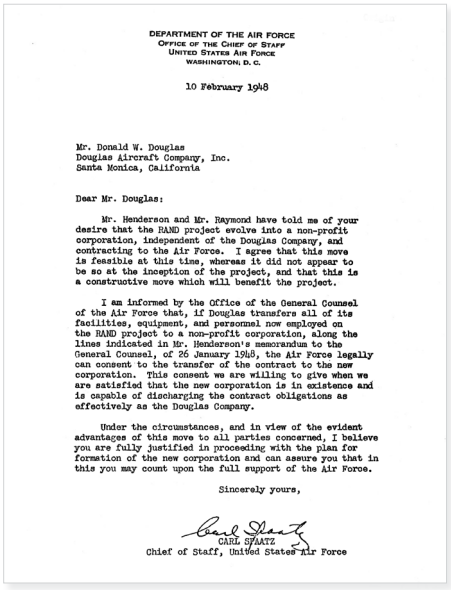
The "Whiz Kids"
Ten officers from the USAAF Office of Statistical Control (front row) were hired by Henry Ford II.

1946

1940s–1950s

Institutionalizing O.R. Talent in the 1950s

Facing the loss of much of the talent he had recruited, General Arnold recognized the need to formalize the synergy between private-sector technology, academic research, and government in the planning for national defense. This led to the creation of a new type of institution that would become the model for modern think tanks: Project RAND (a contraction of "research and development"). Arnold partnered with Donald Douglas of Douglas Aircraft Company, Edward Bowles of MIT, and others to found Project RAND in 1945. RAND published its first report, *Preliminary Design of an Experimental World-Circling Spaceship*, in May 1946, which helped lay the foundation for Air Force space operations. In May 1948, at the direction of the U.S. Air Force Chief of Staff, Project RAND was transferred to the RAND Corporation, an independent nonprofit organization (it remains today as RAND Project AIR FORCE, the Air Force's sole federally funded research and development center for studies and analyses). Under Air Force guidance and sponsorship, RAND has played a central role in the formation and definition of the disciplines of O.R. and systems analysis. The breadth of the Air Force's mandate to RAND—its involvement in almost every aspect of Air Force operations—allowed RAND researchers to build a foundation of specialized studies over many years that formed the basis for its broader policy analysis. The latitude granted RAND in defining its research agenda led to foundational work that still forms the basis of O.R. today. The simplex method, game theory, Monte Carlo techniques, dynamic programming, conceptual approaches to defining and quantifying cost and risk—all were developed or first practically applied at RAND. The RAND Corporation has grown from a project with a staff of 200 serving the Air Force as its single client to the world's eighth-ranked think tank serving thousands of clients with a staff of 1,875 (RAND, 2016; McGann, 2016).



DEPARTMENT OF THE AIR FORCE
OFFICE OF THE CHIEF OF STAFF
UNITED STATES AIR FORCE
WASHINGTON, D. C.

10 February 1948

Mr. Donald W. Douglas
Douglas Aircraft Company, Inc.
Santa Monica, California

Dear Mr. Douglas:

Mr. Henderson and Mr. Raymond have told me of your desire that the RAND project evolve into a non-profit corporation, independent of the Douglas Company, and contracting to the Air Force. I agree that this move is feasible at this time, whereas it did not appear to be so at the inception of the project, and that this is a constructive move which will benefit the project.

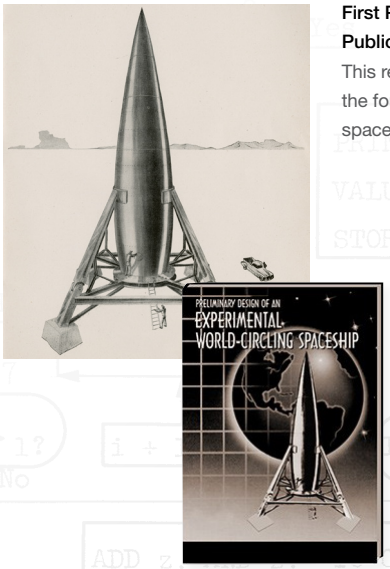
I am informed by the Office of the General Counsel of the Air Force that, if Douglas transfers all of its facilities, equipment, and personnel now employed on the RAND project to a non-profit corporation, along the lines indicated in Mr. Henderson's memorandum to the General Counsel, of 26 January 1948, the Air Force legally can consent to the transfer of the contract to the new corporation. This consent we are willing to give when we are satisfied that the new corporation is in existence and is capable of discharging the contract obligations as effectively as the Douglas Company.

Under the circumstances, and in view of the evident advantages of this move to all parties concerned, I believe you are fully justified in proceeding with the plan for formation of the new corporation and can assure you that in this you may count upon the full support of the Air Force.

Sincerely yours,

CARL SPAATZ
Chief of Staff, United States Air Force

Project RAND
Founded by a partnership between Gen. Arnold, Donald Douglas of Douglas Aircraft Company, Edward Bowles of MIT, and others.



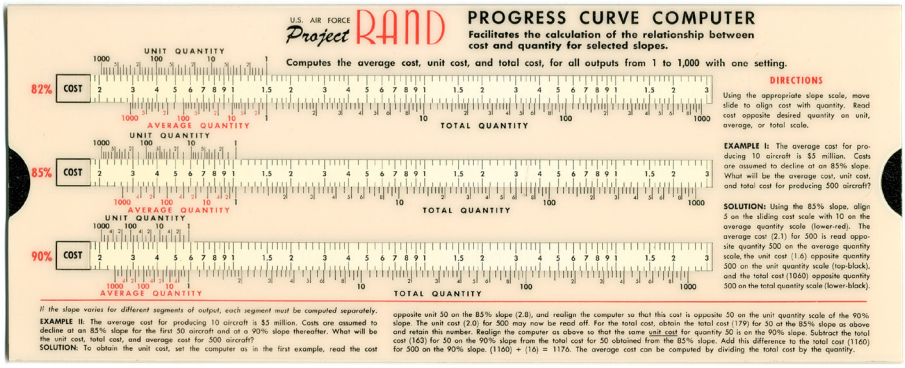
First Project RAND Publication
This research helped lay the foundation for Air Force space operations.

RAND Project AIR FORCE
FFRDC established

1945 **1946** **1948**

1940s–1950s

Institutionalizing O.R. Talent in the 1950s


U.S. AIR FORCE Project RAND

PROGRESS CURVE COMPUTER

Facilitates the calculation of the relationship between cost and quantity for selected slopes.

Computes the average cost, unit cost, and total cost, for all outputs from 1 to 1,000 with one setting.

DIRECTIONS

Using the appropriate slope scale, move slide to align cost with quantity. Read cost opposite desired quantity on unit, average, or total scale.

82% COST

85% COST

90% COST

UNIT QUANTITY

AVERAGE QUANTITY

TOTAL QUANTITY

EXAMPLE I: The average cost for producing 10 aircraft is $5 million. Costs are assumed to decline at an 85% slope. What will be the average cost, unit cost, and total cost for producing 500 aircraft?

SOLUTION: Using the 85% slope, align 5 on the sliding cost scale with 10 on the average quantity scale (lower-red). The average cost (2.1) for 500 is read opposite quantity 500 on the average quantity scale, the unit cost (1.6) opposite quantity 500 on the unit quantity scale (top-black), and the total cost (1060) opposite quantity 500 on the total quantity scale (lower-black).

If the slope varies for different segments of output, each segment must be computed separately.

EXAMPLE II: The average cost for producing 10 aircraft is $5 million. Costs are assumed to decline at an 85% slope for the first 50 aircraft and at a 90% slope thereafter. What will be the unit cost, total cost, and average cost for 500 aircraft?

SOLUTION: To obtain the unit cost, set the computer as in the first example, read the cost opposite unit 50 on the 85% slope (2.8), and realign the computer so that this cost is opposite 50 on the unit quantity scale of the 90% slope. The unit cost (2.0) for 500 may now be read off. For the total cost, obtain the total cost (179) for 50 at the 85% slope as above and retain this number. Realign the computer as above so that the same unit cost for quantity 50 is on the 90% slope. Subtract the total cost (163) for 50 on the 90% slope from the total cost for 50 obtained from the 85% slope. Add this difference to the total cost (1160) for 500 on the 90% slope. (1160) + (16) = 1176. The average cost can be computed by dividing the total cost by the quantity.

RAND Progress Curve Computer
(top) The computer was developed in 1959, allowing the Air Force to calculate how much it should be paying for large orders of military aircraft.

At the same time that General Arnold created Project RAND, the Air Force (an independent service as of 1947) created an internal structure for O.R. within the headquarters and major commands. The Air Force Headquarters unit had two functions: to furnish scientific analyses to the Air Staff and to serve as a focal point in the Air Force–wide OA organization.


Strategic Air Command Headquarters, 1951 (approx.).

By 1951 there were OA sections in ten field commands plus one OA section in the headquarters. As a stable postwar program was established, the number of analysts grew. By 1951 there were 70 assigned, with 95 authorized. The 95 authorized professional positions were mostly civilian, as at that time there were few uniformed analysts available. General Curtis LeMay recruited many preeminent O.R. analysts to his Strategic Air Command Headquarters in Omaha, Nebraska (Zimmerman, 1988). Since the RAND Corporation's work emphasized problems of the far future, the Air Force's OA offices were able to work primarily on current and near-term problems. However, when analysts were needed in the Korean War, some came from RAND, as well as from the OA units.


Richard Bellman's *An Introduction to the Theory of Dynamic Programming* (RAND, R-245), published in 1953, is foundational to the field.

By the mid-1950s, the headquarters OA office had 25 professional positions divided among five teams. Two of the teams were primarily concerned with implications of new types of weapons: one with nuclear weapons and one with ballistic and cruise missiles. A third team dealt primarily with deriving information about combat operations from operational tests and exercises. A fourth team integrated inputs from the previous three teams to use in assisting Air Staff planners. The fifth team maintained liaison with the existing field OA offices and helped commanders who wished to establish new field offices where they did not yet exist. The field OA offices were organized according to these same general principles. Some analysts were available to study combat operations and related problems, while others were tasked with understanding new technologies and their implications for future weapon systems. Most of the growth in the OA program at that time came through the establishment of new offices, rather than the enlargement of existing offices.

1953

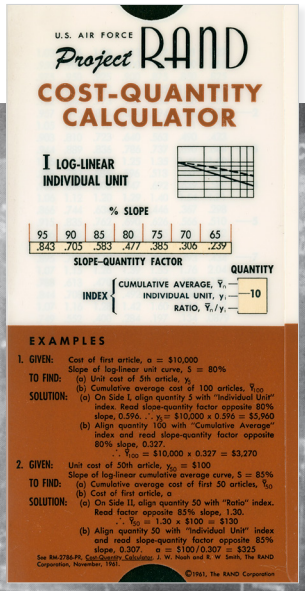
1960s

Force Structure Analysis and Vietnam in the 1960s

The situation changed markedly in the 1960s, when Secretary of Defense Robert McNamara of the Kennedy administration institutionalized systems analysis (used to denote O.R. on broad systems problems) within the Office of the Secretary of Defense (OSD). Many RAND analysts, particularly those developing nuclear deterrence theory, became McNamara's "whiz kids," as he was once Henry Ford's. These government civilian analysts greatly affected the force structure choices in the military service budgets. Their efforts dramatically increased the demand for cost-effectiveness studies from the military services. One of the most significant studies commissioned by Secretary McNamara was led by then Air Force Brigadier General Glenn Kent under Dr. Harold Brown, then Director of Defense Research and Engineering. At a time when almost all Air Force general officers were pilots, Glenn Kent rose to the rank of lieutenant general because his analyses helped the Air Force justify its positions to an increasingly analytically minded Defense Department. Lieutenant General Kent's study concluded that "neither the United States nor the Soviet Union could avoid national destruction in an all-out thermonuclear exchange" (Brown, 2008). This work formed the basis for much of the U.S. nuclear defense policy and treaty negotiations for the next 27 years.

> **....neither the United States nor the Soviet Union could avoid national destruction in an all-out thermonuclear exchange.**
>
> — **Lieutenant General Glen Kent**
> United States Air Force

Gen. Glen Kent
Gen Kent's analysis formed the basis for future U.S. nuclear defense policy.



The Cost-Quantity Calculator
RAND Project AIR FORCE produced the calculator in 1961 to help the U.S. Air Force determine how much they should be paying for large orders of military equipment.

Simulated Air Defense Center
Air Force crews learned new defense techniques during the simulations—and simultaneously helped researchers find new training methods for other Air Force crews.

1960 **1961**

1960s

Force Structure Analysis and Vietnam in the 1960s

Seventh Air Force Headquarters
(top) Tan Son Nhut Air Base, Vietnam, 1962.

The Vietnam War required analysis to support both day-to-day operations in theater and longer-term studies. The Pentagon Studies and Analyses office was busy conducting force structure analyses to support budget decisions and was a long distance from operational decisions; hence, a small group of O.R. professionals worked at the Seventh Air Force Headquarters in Vietnam. These analysts presented daily briefings containing trend analysis and truck kill projections to the director of operations and the commander to inform decisionmaking for the upcoming week. These weekly analyses also investigated truck kill claims and battle damage assessment. In 1970, the air sortie debrief reports were incorporated into the Southeast Asia Database to support better analysis. Their principal O.R. tool was regression analysis to project future results. This analysis cell also conducted special-purpose studies and explored subjects such as the effectiveness of the Black Crow system, a highly sensitive passive sensor deployed on AC-130 aircraft that could detect North Vietnamese trucks hidden under the dense jungle canopy along the Ho Chi Minh trail. Finally, the office compiled a comprehensive history of the Southeast Asia war in the annual Commando Hunt reports.

The Black Crow antenna mounted on an AC-130A. Air Force O.R. analysts found that this sensor could be effective at detecting North Vietnamese trucks hidden under jungle canopy.

Under Air Force sponsorship, RAND brought O.R. techniques to a host of tactical and strategic questions throughout the Vietnam era. This included a ground-breaking analysis of the motivations and morale of Viet Cong fighters, which was carried out largely by RAND analysts using testimony from Viet Cong prisoners and deserters. The Air Force and the U.S. Military Assistance Command, Vietnam (MACV), relied on this and other RAND analyses throughout the war (Elliott, 2010).

MACV Headquarters
"Pentagon East" at Tan Son Nhut

The Air Force's OA organization continued to grow during this period. The legacy of Project SCOOP became the basis of a new and larger Pentagon organization called Air Force Studies and Analyses. The newer office of Studies and Analyses and the smaller headquarters OA office (about 35 professionals at that time) both reported at high levels,

1969

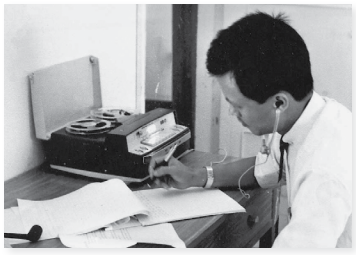
1960s

Force Structure Analysis and Vietnam in the 1960s

required the same kind of competent analysts, and applied the same O.R. techniques. These similarities suggested the merger of the smaller OA headquarters office into the larger Studies and Analyses office, which was finally accomplished in 1971. This organization would become the Air Force Studies and Analysis Agency (AFSAA) in 1991. The new organizational structure led to the employment of more advanced computer simulation models and their application in larger analytic studies.

AFSAA served informally as an O.R. focal point for professionalizing defense-related analytics. Technical exchanges across the Air Force continued in the course of business and at meetings of professional societies. Initially, the Air Force analysts held a semi-annual OA technical symposium; however, these were discontinued as the Air Force made increasing use of the multi-service classified symposia of the Military Operations Research Society (MORS). The Air Force was one of the founding organizational sponsors when MORS was incorporated in 1966.

MORS
Incorporated in 1966, the Air Force was one of the founding sponsors.



Transcribing a Taped Interview
Thang was part of the RAND staff working as an interviewer operating in Southeast Asia.

* * *

I was young at that time; therefore, I had to join those [VM] organizations. Had I not, I would have found myself left behind, because all my friends joined them.

* * *

[By one who joined the Viet Minh in 1949, when the war spread to his region]. . . . my friends asked me to come along. My wife also urged me, and the conditions of the times favored my joining.

* * *

I lived with my grandparents and my uncle. After my grandparents died, in 1948, my uncle left for the Resistance and took me with him.

And the son of a highly-regarded Vietnamese Communist, whose father had died in 1943 and who was trained and used by the Viet Minh from the age of thirteen on, commented with apparent pride on [illegible] Party elders in his province with [illegible] when he was seventeen "recalled the na[illegible] when

Viet Cong Recruitment: Why and How Men Join
Excerpt of testimony used to analyze the motivations and morale of Viet Cong fighters.

1966 **1967**

1970 – 1980s

The Cold War in the 1970s and 1980s

The 1970s and 1980s saw the expansion of O.R.'s role in many areas of defense planning, budgeting, and operations and the advent of new methodologies to address these needs. The Air Force remained a leader in this area.

One such innovation was the creation of "strategies-to-tasks" analysis. Lieutenant General Kent faced a major challenge in the summer of 1970 while the Senate debated the 1971 Defense Authorization Bill. Cost overruns on the new strategic airlift C-5A program led to the removal of all funding for that program as well as the F-15 and the Airborne Warning and Control System (AWACS) programs. Air Force Chief of Staff General John Ryan directed Lieutenant General Kent to prepare sound analytic evaluations of all three programs for congressional review. Lieutenant General Kent's "strategies to tasks" analyses of the three programs won over the objections of Senator William Proxmire, who withdrew his amendment to stop these programs. Today all three programs continue as key components of U.S. and allied defense departments (Kent et al., 2008). Lieutenant General Glenn Kent, who led the Air Force Studies and Analyses Agency (for four of his 33 Air Force years) and later worked an additional 20 years at RAND, summarizes several of the analytical approaches in his analytical memoir (Kent et al., 2008).

AWACS — 1977
Prior to AWACS' first flight.

AWACS Today
An E-3 Sentry from Tinker Air Force Base, Okla., taxis on the flightline at Davis-Monthan Air Force Base, Ariz., May 16, 2015.

1977

1970s–1980s

The Cold War in the 1970s and 1980s

O.R. also played a significant role in shaping aircraft designs to meet new operational challenges. Based on O.R. analysis, the Air Force replaced the aging F-4, F-100, and F-105 fighters with the F-15 and the F-16. These new aircraft of the 1970s and 1980s were to become the dominant weapon systems NATO used to counter the Soviet threat. A key figure in this era was Larry D. Welch. He served as a major, lieutenant colonel, and colonel in Headquarters Air Force Studies and Analyses, and later as the Twelfth Air Force Chief of Staff. Lieutenant General Kent had 200 analysts in Studies and Analyses, with 37 under Welch's Fighter Division. Welch led the analytic effort that was crucial to the design and acquisition of the F-15 air superiority fighter and the lighter-weight and less expensive air-to-air and air-to-ground F-16. Welch teamed with Headquarters Air Force Research and Development Requirements Major (later Colonel) John Boyd and Air Force Systems Command (AFSC) mathematician Thomas P. Christie in the application of Monte Carlo simulation models and the energy maneuverability concept that played a critical role in shaping the design parameters of the F-15 and the F-16. The weight, wing loading, and thrust-to-weight ratio of the F-15 fielded by the Air Force in 1974 were within 5 percent of the most cost-effective design of the Welch simulation. Welch's Fortran IV–coded simulation for the F-4, F-15, and F-16 was the basis of the "TAC AVENGER" model (Welch, 2004). Air Force Studies and Analyses used this model for evaluations of the A-10, the F-4G, the EF-111, and the AWACS aircraft.

NAME: TACTICAL AIR CAPABILITIES, AVIONICS, ENERGY MANEUVERABILITY EVALUATION AND RESEARCH (TAC AVENGER)

DESCRIPTION: The TAC AVENGER Model is a digital computer simulation of two aircraft in a close-in maneuvering air duel. In this simulation, each aircraft maneuvers in three dimensions; each pilot reacts on a second-by-second basis to

General Larry D. Welch
As a major and lieutenant colonel, Welch led the analytic effort that was crucial to the design and acquisition of the Air Force's F-15 and F-16 aircraft.

F-100 Super Sabre

F-4 Phantom

F-16

F-15

Acquisition of New Aircraft
Based on O.R. analysis, the Air Force replaced the aging F-4, F-100, and F-105 fighters with the F-15 and F-16.

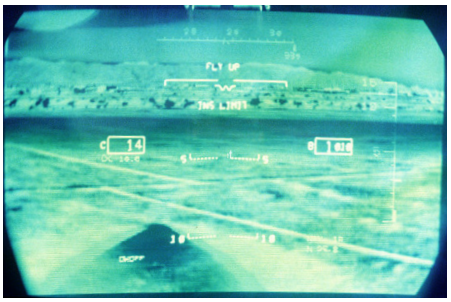
1979 **1980s**

1970s–1980s

The Cold War in the 1970s and 1980s

The continued evolution of threats during the Cold War demanded a systematic way to evaluate possible gaps in U.S. capabilities. As a major general and director of plans at the Tactical Air Command, Larry Welch developed an analysis team with his AFSC counterpart. This team's objective was to identify required defense capabilities and possible gaps in existing capabilities. This gap analysis approach led to the development and fielding of the first generation stealth aircraft, the F-117, to defeat the new Soviet SA-5 surface-to-air-missile and the Warsaw Pact integrated air defense system. This gap analysis partnership also led to the EC-130H Compass Call system to disrupt adversary communications, the F-15E long-range and all-weather strike program, and the LANTIRN (Low Altitude Navigation and Targeting Infrared for Night) system.

As Air Force Chief of Staff, General Welch continued to rely on sound analytic principles. In soliciting industry proposals for the F-22 fighter, the Air Force stipulated use of the Tactical Air Combat "BRAWLER" engagement-level simulation model for source selection. Welch justified the nuclear-capable Advanced Cruise Missile based on analysis of penetration to targets deep in the Soviet Union.



LANTIRN
An F-15E heads-up display of infrared image from the AN/AAQ-13 LANTIRN navigation pod.

At the Air Staff, the bulk of the studies dealt with future weapon systems and future force posture. The occurrence of many highly classified studies of advanced systems began and continues today. Many studies evaluated weapon systems exploiting the latest technology, and the difference in emphasis between RAND and the in-house Air Force analytical offices that had prevailed in the 1950s diminished, to a large extent because of the impact of the institutionalization of systems analysis in the Department of Defense.

Through the 1970s and 1980s, many Air Force and joint analysis efforts remained focused on the Soviet nuclear threat. Three main organizations focused extensive resources on nuclear warfare analyses: Strategic Air Command, AFSAA, and the Joint Chiefs of Staff J8 Directorate of Force Structure, Resources, and Assessment. The Strategic Air Command Headquarters at Omaha, Nebraska, maintained a centralized civilian analysis organization along with military analysis shops in each of the functional areas, while AFSAA dedicated a third of its analysts to evaluating nuclear war. These three analysis offices annually conducted and compared detailed plans of potential Soviet massive nuclear attacks on

Compass Call
The EC-130H Compass Call is an airborne tactical weapon system using a modified version of the C-130 Hercules airframe.

The Air Force approved full-rate production of the LANTIRN navigation pod in November 1986.

of NATO's desire to emphasize coupling between
and the theater. But as new issues are addressed
adjustments in this division of labor may be
savings in force size and structure.

The above discussion and criteria help
assessing the future nuclear deterrent needs of
this paper addresses these needs more
the force direction capability, and the nuclear

THE FORCE STRUCTURE ISSUES

The following discussion is organized in terms of the range categories and of the basing of nuclear forces--in Europe (TNF), offshore, and in the United States.[10]

[9] This paper deals explicitly with nuclear force needs. Such a focus is not meant to suggest that conventional force needs are

1982 **1983** **1986**

1970s–1980s

The Cold War in the 1970s and 1980s

U.S. Air Force Academy graduation (top)

To date: 1,190 O.R. degrees conferred

Air Force Institute of Technology graduation

To date: 1,262 master's degrees and 63 doctorates in O.R. conferred

In 1978, the U.S. Air Force Academy was one of the first universities to offer O.R. as an undergraduate major.

the United States and planned response options. The predominant approaches were linear programming and discrete-event simulations. These studies provided the foundation for force structure decisions including requirements and acquisitions. RAND Project AIR FORCE pioneered work on attacking air bases. It also examined ballistic missile options along with their potential basing, and its analysis of the Soviet Union and arms control laid the foundations for many treaties.

During this period, the Air Force continued to help professionalize O.R., particularly in its educational programs. The Air Force Institute of Technology started conferring an O.R. specialty for master's degrees in 1973 and doctorates in 1992. To date, it has conferred 1,262 master's degrees in O.R. and closely related programs and 63 doctorates in O.R. In 1978, the U.S. Air Force Academy was one of the first universities to offer O.R. as an undergraduate major; the major continues to be interdisciplinary, with courses from the Departments of Mathematical Sciences, Management, Economics and Geography, and Computer Science. The Air Force Academy had conferred 1,190 degrees to O.R. majors through 2016. The Air Force Academy was one of the three finalists for the 2016 INFORMS UPS George D. Smith Prize, which is awarded annually to an academic department or program for effective and innovative preparation of students to be good practitioners of O.R., management science, or analytics.

The total number of Air Force analysts generally continued to increase, at a somewhat slower rate, through the mid-1980s. In 1988, an Air Force personnel database showed 476 civilian analysts in the O.R. analyst career series. Under President Ronald Reagan, Defense Department budgets peaked in 1986, and then began a general decline in the size of the Department of Defense, including military O.R. analysts. In 1986, the Air Force had 1,626 military scientists with approximately 60 percent of those being O.R. analysts. By the end 2000, Air Force civilian levels in career series relevant to analysis were about 20 percent lower than in 1988. After the turn of the century, the number of analysts began to increase. The Air Force had increased to 563 civilian O.R. analysts in 2015. The Air Force completed 2015 with 492 military O.R. analysts. In addition, because of the mathematical requirements for O.R., the Air Force converted approximately 200 cost analysts into O.R. positions.

1978

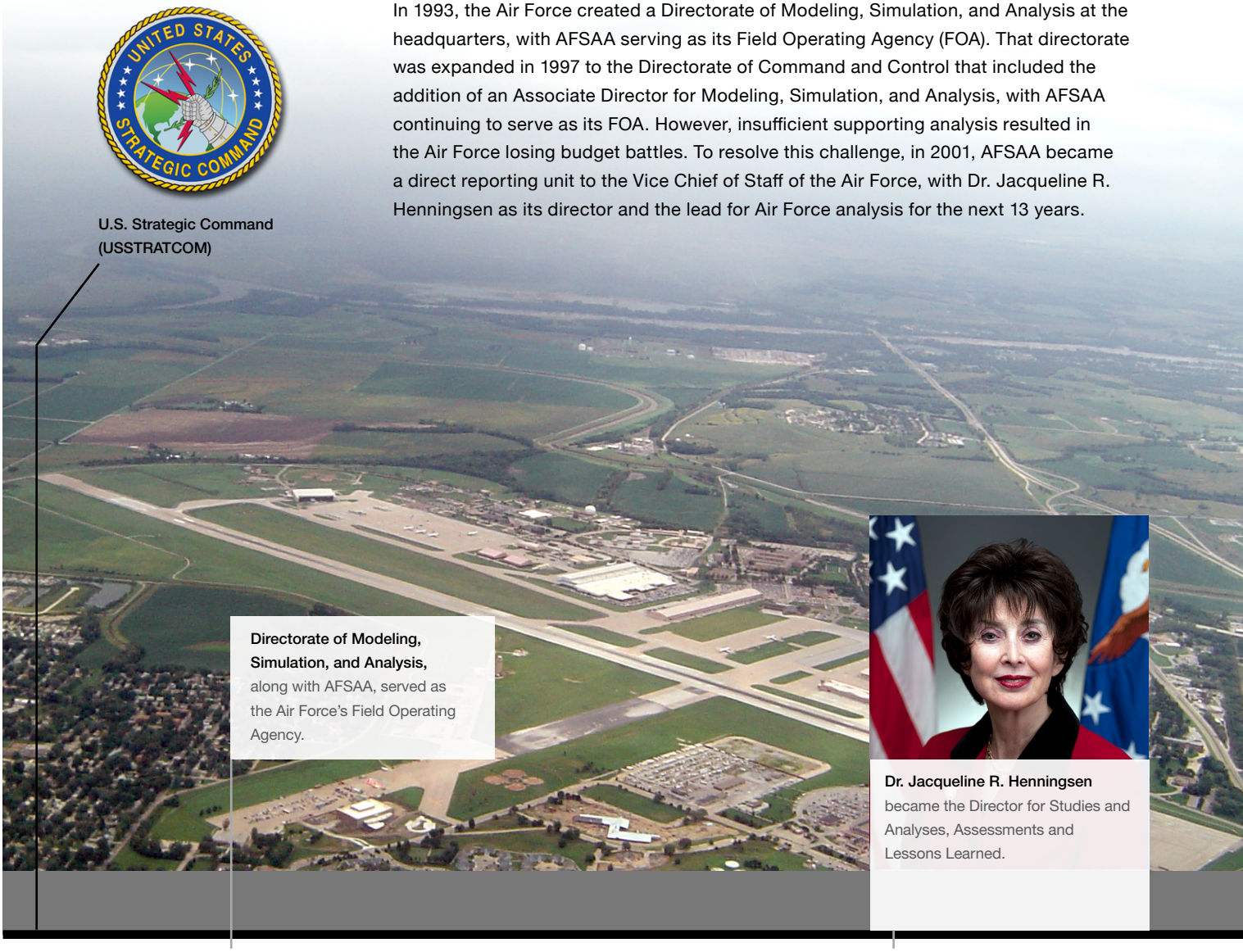
1990-2005

The Mideast Wars in the 1990s Through 2005

With the end of the Cold War, the Air Force shifted its primary focus from strategic bombing to fighter operations. In 1992, Strategic Air Command was disestablished and a joint U.S. Strategic Command was established at Offutt Air Force Base, Nebraska. Continuing the legacy from General LeMay, this combatant command continued to have a stronger presence and reliance on O.R. analysts than the other combatant commands. While the major commands were realigned, the Air Staff was also reorganized. In 1991, the O.R. organization was renamed the Air Force Studies and Analyses Agency (AFSAA), which reported to the Air Staff. This alignment remained throughout the 1990s.

In 1993, the Air Force created a Directorate of Modeling, Simulation, and Analysis at the headquarters, with AFSAA serving as its Field Operating Agency (FOA). That directorate was expanded in 1997 to the Directorate of Command and Control that included the addition of an Associate Director for Modeling, Simulation, and Analysis, with AFSAA continuing to serve as its FOA. However, insufficient supporting analysis resulted in the Air Force losing budget battles. To resolve this challenge, in 2001, AFSAA became a direct reporting unit to the Vice Chief of Staff of the Air Force, with Dr. Jacqueline R. Henningsen as its director and the lead for Air Force analysis for the next 13 years.

U.S. Strategic Command (USSTRATCOM)



Directorate of Modeling, Simulation, and Analysis, along with AFSAA, served as the Air Force's Field Operating Agency.

Dr. Jacqueline R. Henningsen became the Director for Studies and Analyses, Assessments and Lessons Learned.

1992 **1993** **2001**

1990s-2005

The Mideast Wars

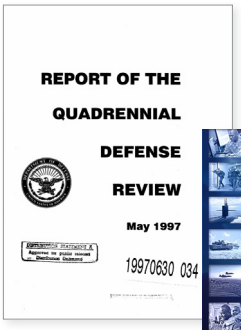
The First Gulf War in 1991 extensively employed members from AFSAA in build-up deliberations conducted by the "Black Hole Team." This war demonstrated the value of Air Force investments in stealth, precision weapons, and night sensors, which enabled a new effective approach to air war.

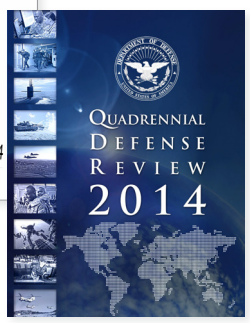
Despite the post–Cold War drawdown in defense budgets, the need for O.R. to illuminate capability requirements and to clarify difficult force trade-offs remained strong. In 1993, under Defense Secretary Les Aspin, the Department of Defense completed the Bottom-Up Review to adjust the National Defense Strategy in light of the uncertainty following the end of the Cold War. Congress decided to mandate these episodic reports, which became the Quadrennial Defense Reviews (QDRs), for each new presidential administration. The Air Force has contributed significant force structure analyses in support of this and all subsequent QDRs.

The terror attacks on September 11, 2001, and ensuing operations—the Global War on Terrorism, the war in Afghanistan (Operation Enduring Freedom), and the war in Iraq (Operation Iraqi Freedom)—brought new challenges and increasing demand for Air Force operations analysis. September 11 required the defense community to rapidly shift its attention to the global terrorist threat and counterterrorism operations. The Air Force was able to draw on a large body of existing RAND analyses—testament to the Air Force's patient, even prescient, investment in O.R. over many years.

As in previous conflicts, the Air Force deployed "combat analysts" to support operational commanders. They provided insights on a wide range of issues, including studies on the response time of close air support sorties to embattled ground commanders, the effectiveness of measures intended to defeat improvised explosive devices, and the effectiveness of measures to reduce civilian casualties in close proximity to combat situations. With these wartime experiences, career military O.R. analysts were more frequently promoted to colonel. Once again, O.R. experienced more than a decade of growing influence in the Air Force.

F-117A Nighthawk Stealth Fighters
The F-117A aircraft from the 37th Tactical Fighter Wing, Tonopah Test Range, Nev., line the runway while deploying to Saudi Arabia during Operation Desert Shield.





Quadrennial Defense Review (QDR)
Air Force force structure analyses are a significant input to the QDR.

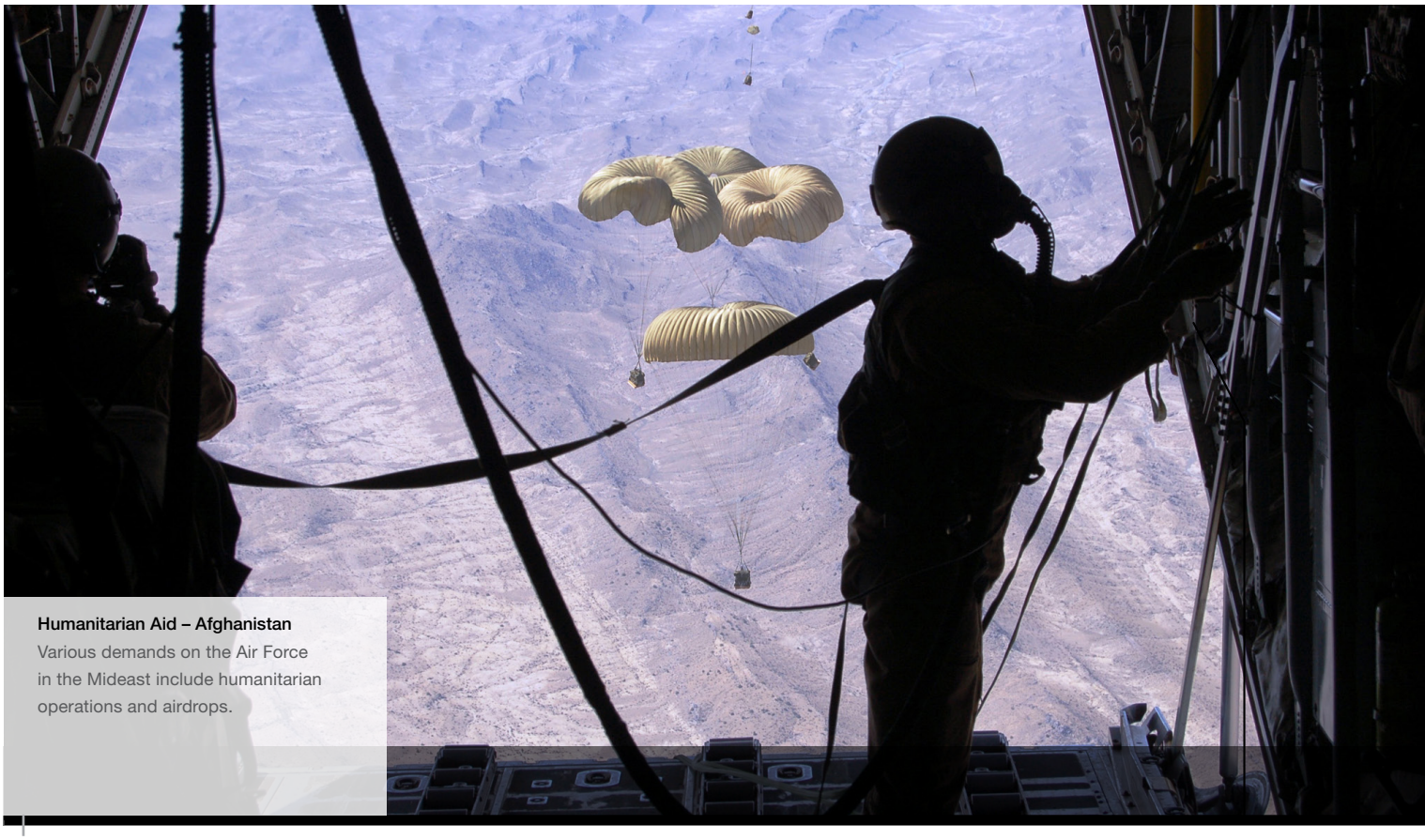
1991 **1997**

2006–Present

The Mideast Wars and O.R. Reorganization

The wars in the Mideast perpetuated a new paradigm in national security, consisting of multiple, often concurrent commitments. These engagements might occur anywhere on the globe at any time and range in intensity from limited humanitarian operations to full-scale theater warfare. The various demands for Air Force capabilities have been met by rotating forces into the conflict zones. Inherent uncertainty concerning time, place, and adversary has led to production and regular revision of many planning scenarios. This evolution of force planning to reflect the new geopolitical environments has led to a renewed and expanded emphasis on analytic support for force development and deployment.

One of the major O.R. efforts in support of Operations Enduring Freedom and Iraqi Freedom was the improvement of aerial resupply of our combat forces. The Warner Robbins Air Logistics Center used "Critical Chain" project management techniques to reduce the time required to repair and overhaul the C-5 transport aircraft by 33 percent, increasing the effective C-5 fleet capacity by nearly 10 percent. The Institute for Operations Research and the Management Sciences (INFORMS) recognized Warner Robbins with the 2006 Franz Edelman Award.



Humanitarian Aid – Afghanistan
Various demands on the Air Force in the Mideast include humanitarian operations and airdrops.

2007

2006-Present

The Mideast Wars and O.R. Reorganization

The U.S. Air Force O.R. Awards section of this nomination details the extensive history of formal recognitions of Air Force O.R. contributions.

In 2006, the O.R. organization became an Air Staff directorate, designated AF/A9, reporting to the Chief of Staff of the Air Force. Dr. Henningsen became the first director of AF/A9 and led Air Force analysis until 2014, when she was succeeded by Kevin Williams. In 2006, each of the major commands also established an A9 office overseeing its studies and analyses, assessments, and lessons learned and as a focal point for O.R. The equal status of O.R. within the Air Staff enabled supporting a wide range of decisions across manpower, operations, planning, and resources. Like the combat analysts, the A9 structure returned Air Force O.R. to its World War II roots—major commanders throughout the Air Force once again had a direct report responsible for analysis.

The differences between the services, Joint Staff, and OSD led to the formulation of standard scenario and campaign model inputs in the Analytical Agenda, which began in 2006. In 2010, the name was changed to Support for Strategic Analysis. The Air Force developed the Synthetic Theater Operations Research Model (STORM), a discrete-event simulation of about 2 million lines of C code, which was started in the late 1990s and became the standard campaign model for the Air Force, Navy, and Marine Corps by 2010.

In 2014, as part of the headquarters manpower reductions, the responsibility to act as the Executive Agent for RAND Project AIR FORCE was assigned to AF/A9.

C-5 Galaxy at Warner Robins Air Logistics Center
Programmed depot-level maintenance on the C-5 by aircraft mechanics.

Combined Air and Space Operations Center
Red Flag was the first exercise that truly integrated advanced operational and tactical air, space, and cyber training in a live, simulated, constructive environment.

Analysis, Assessments, and Lessons Learned Awards Ceremony – 2014
Kevin E. Williams, Director, Air Force Studies, Analyses, and Assessments, presents a certificate to Dr. Jacqueline R. Henningsen, celebrating the renaming of the Air Force O.R. Lifetime Achievement Award as the Dr. Jacqueline R. Henningsen Air Force Analyst Lifetime Achievement Award.

2006 **2014**

Summary

Air Force leaders have employed O.R. to inform their most important decisions for the past 75 years. General "Hap" Arnold directed the formation of Operations Analysis sections throughout the Army Air Forces in 1942 and co-founded project RAND in 1945. Dr. George B. Dantzig's development of the simplex method in 1947 to optimize linear programming problems enhanced the Air Force's and world's ability to rapidly investigate many complex issues. Throughout the 1960s and 1970s, Lieutenant General Glenn Kent used mathematical models to inform a generation of statesmen and commanders on nuclear policy decisions and investment strategies. General Larry Welch, with others, applied O.R. analyses to establish the requirements that specified the modern aircraft and systems throughout the 1970s and 1980s that are still the backbone of the Air Force. From this foundation, O.R. analysts and O.R.-trained leaders continue to operate throughout the Air Force, underpinning the most important resource commitments and personnel employment decisions with sound analytics.

REFERENCES

Brothers, L. A., *Operations Analysis in World War II, United States Army Air Forces*, Philadelphia: Stevenson-Brothers, 1948.

Brothers, L. A., "Development of Operations Analysis," Working Paper 17.1.4, Operations Analysis Division, Directorate of Operations, Headquarters, U.S. Air Force, Washington, D.C., 1951.

Brothers, L. A., "Operations Analysis in the U.S. Air Force," *Operations Research*, Vol. 2, pp. 1–16, 1954.

Brown, Harold, foreword to Glenn A. Kent, David Ochmanek, Michael Spirtas, and Bruce R. Pirnie, *Thinking About America's Defense: An Analytic Memoir*, Santa Monica, Calif.: RAND Corporation, OP-223-AF, 2008: http://www.rand.org/pubs/occasional_papers/OP223.html

Cottle, Richard, Ellis Johnson, and Roger Wets, "George B. Dantzig (1914–2005)," *Notices of the AMS*, Vol. 54, No. 3, pp. 343–362, 2007.

Dongarra, J., and F. Sullivan, "Top Ten Algorithms of the Century," *Computing in Science and Engineering*, Vol. 2, No. 1, pp. 22–23, January/February 2000.

Elliott, Mai, *RAND in Southeast Asia: A History of the Vietnam War Era*, Santa Monica, Calif.: RAND Corporation, CP-564-RC, 2010.

Gass, S. I., "The First Linear-Programming Shoppe," *Operations Research*, Vol. 50, No. 1, pp. 61–68, 2002.

Kent, Glenn A., David Ochmanek, Michael Spirtas, and Bruce R. Pirnie, *Thinking About America's Defense: An Analytic Memoir*, Santa Monica, Calif.: RAND Corporation, OP-223-AF, 2008: www.rand.org/t/OP223

Leach, Major Walter Barton, and Ward E. Davidson, "Memorandum: Operations Research in England," Joint New Weapons Committee, Washington, D.C.: Joint Chiefs of Staff, 1942.

McArthur, C. W., *Operations Analysis in the U.S. Army Eighth Air Force in World War II*, History of Mathematics, Vol. 4, Providence, R.I.: American Mathematical Society, 1990.

McGann, J. G., *2015 Global Go to Think Tank Index Report*, Philadelphia: The Lauder Institute, University of Pennsylvania, 2016.

Miser, H. J., "Craft in Operations Research," *Operations Research*, Vol. 40, No. 4, pp. 633–639, 1992.

Miser, Hugh, "Operations Analysis in the Army Air Forces in World War II: Some Reminiscences," *Interfaces*, October 1, 1993.

RAND Corporation, "A Brief History of RAND," 2016: http://www.rand.org/about/history/a-brief-history-of-rand.html

Shrader, Charles R., ed., *History of Operations Research in the United States Army, Volume 1, 1942–1962*, Washington, D.C.: Office of the Deputy Under Secretary of the Army for Operations Research, 2006: http://www.history.army.mil/html/books/hist_op_research/CMH_70-102-1.pdf

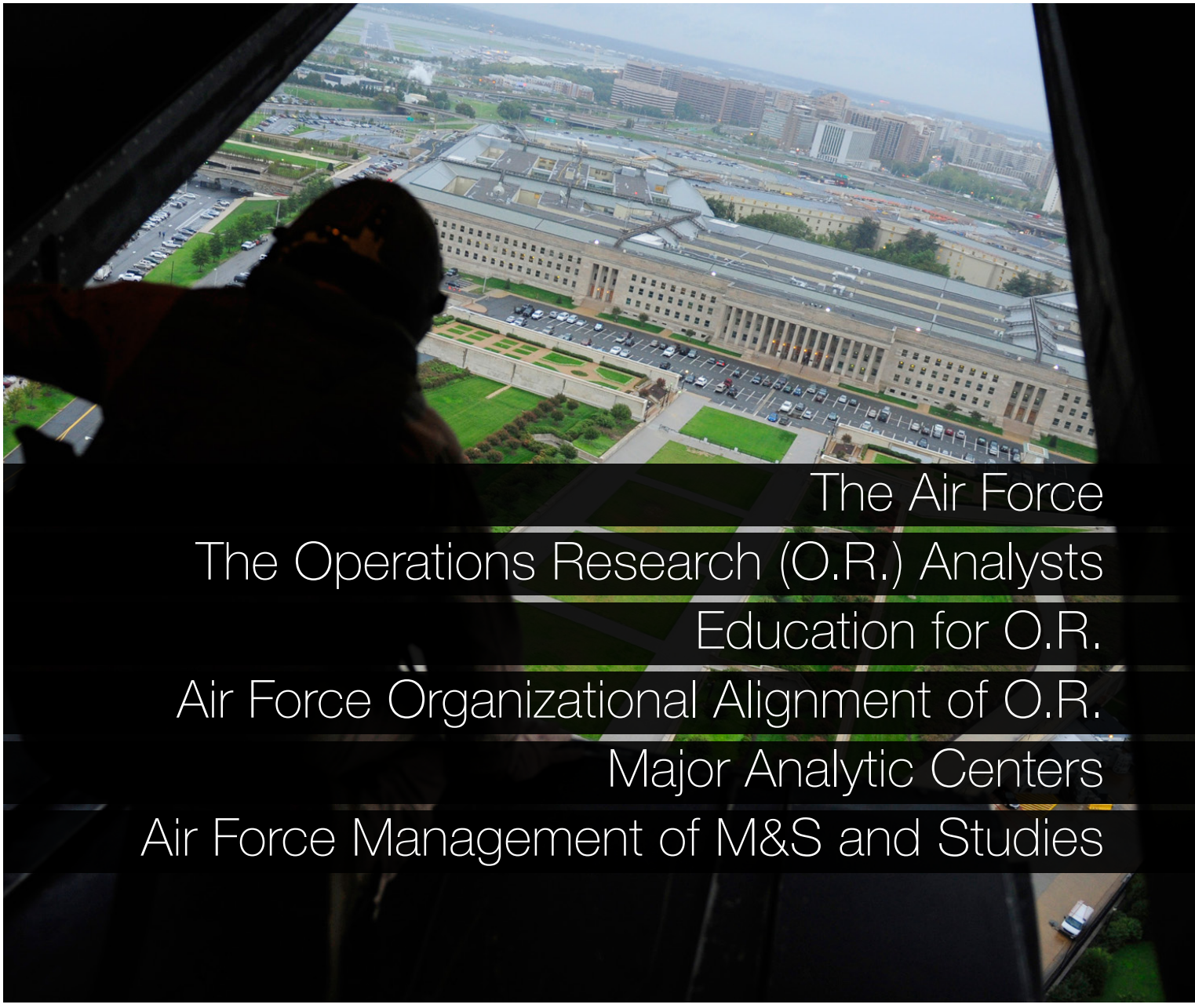
Thomas, Clayton J., Robert S. Sheldon, and Mark A. Gallagher, "Air Force Operations Research," in Saul I. Gass and Michael Fu, eds., *Encyclopedia of Operations Research and Management Science*, 3rd Edition, New York: Springer Publications, 2011, pp. 20–25.

Welch, Larry D., oral history interview by Jim Bexfield, FS, and Bob Sheldon, FS, the Military Operations Research Society and the Institute for Defense Analyses, Alexandria, Va., 2004.

Zimmerman, Carroll L., *Insider at SAC: Operations Analysis Under General LeMay*, Manhattan, Kan.: Sunflower University Press, 1988.

Appendix 4

Organization of Operations Research in the U.S. Air Force



The Air Force

The Operations Research (O.R.) Analysts

Education for O.R.

Air Force Organizational Alignment of O.R.

Major Analytic Centers

Air Force Management of M&S and Studies

Organization of O.R. in the U.S. Air Force

The U.S. Air Force has organized to ensure that O.R. is integrated throughout its structure. This summary has six main sections describing the Air Force, its analysts, education, staff alignment, analytic centers and their missions, and management of models and simulations.

The Air Force

The Air Force is a large, complex organization, with 317,000 active duty military members, 182,819 federal civilian employees, 105,500 National Guard members, and 69,200 military reservists.[1] The Air Force has a budget of $163.1 billion for fiscal year 2016. Air Force analysts provide the qualitative and quantitative analysis for a diverse range of topics, including aircraft sortie generation rates, weapon effectiveness, satellite operations, cyber defenses, recruiting goals, logistics, and budget trade-offs. Analytic insights are routinely used in support of the Secretary and Chief of Staff of the Air Force for their congressional testimonies.

Air Force composition:

- **317,000** active duty military members
- **182,819** federal civilian employees
- **105,500** National Guard members
- **69,200** military reservists

Operations Research Analysts

The Air Force employs 539 active duty, National Guard, and Air Force Reserve O.R. analysts and 849 professional civil service O.R. analysts. The analyst workforce is highly educated: 74 percent of Air Force officers and 73 percent of Air Force civil government analysts have master's degrees, and 16 percent of officers and 6 percent of civilian employees have Ph.D.'s. Additionally, many Air Force engineers and scientists conduct or support O.R. studies.

The Air Force partners at RAND Project AIR FORCE provide 127 congressionally allocated Staff Technical Equivalents (STEs), which corresponds to 250–300 employees, half of whom hold Ph.D.'s. Ninety of the STEs are centrally funded, and the remaining 37 STEs are organizationally funded, with approximately half sponsored by the Air Force Headquarters and the other half sponsored by the major commands.

O.R. analysts composition:

- **539** active duty, National Guard, and Air Force Reserve O.R. analysts
- **849** civilian O.R. analysts
- **~250–300** STE employees at RAND Project AIR FORCE

O.R. analysts education:

- **Master's: 74%** of officers and **73%** of civil servants
- **Ph.D.'s: 16%** of officers and **6%** of civil servants

[1] U.S. Air Force, *Fiscal Year 2017 Budget Overview*, SAF/FMB, February 2016, p. 24.

Education for Operations Research

The graduating class of 2017 at USAFA will bring the total of O.R. baccalaureate recipients to nearly 1,200.

The Pardee RAND Graduate School is the nation's largest public policy Ph.D. program.

The Air Force conducts undergraduate, graduate, and initial skills training in O.R. The initial skills training is a 14-week course conducted with the Army at the Army Logistics University located at Ft. Lee, Virginia. Course content and instructional techniques are designed to provide participants with a knowledge and understanding of military applications of O.R. methodologies. Whereas the Army cross-trains combat officers into the O.R. specialty after about ten years of service, the Air Force accesses O.R. analysts as new lieutenants.

The U.S. Air Force Academy (USAFA) in Colorado Springs, Colorado, offers a major in O.R. Recognizing the interdisciplinary nature of O.R., this rigorous program is taught in the Mathematical Sciences, Economics, Geospatial Sciences, Management, and Computer Science Departments. The USAFA's O.R. curriculum teaches cadets how to use mathematics to model real-world systems, focusing on the operations of organizations. The syllabus includes traditional mathematical modeling methods, such as statistics and probability, as well as mathematical programming and queuing theory. Students learn to develop and apply quantitative modeling methods to real management and economics problems. Each year, the Academy awards Bachelor of Science degrees in O.R. to more than 30 high-caliber cadets. The graduating class of 2017 will bring the total of O.R. baccalaureate recipients to nearly 1,200.

The Air Force Institute of Technology (AFIT), located in Dayton, Ohio, offers both a Master of Science and a Doctor of Philosophy in O.R. and is focused on defense-related analytic issues. This nationally recognized institute has introduced more than 17,500 graduate and 600 doctoral Ph.D. recipients into the Air Force and its sister services since its inception in November of 1919. AFIT accepts both military and civil service employee applicants to its graduate and postgraduate programs.

In addition to the Air Force's organic O.R. educational opportunities, the RAND Corporation, one of the Air Force's premier partners in analysis, offers a Ph.D. in public policy analysis at the Pardee RAND Graduate School, founded in 1970 as one of the original eight graduate programs in public policy analysis, and the only program with a Ph.D. It is the only graduate school based at a public policy research institute. The Pardee RAND Graduate School is the nation's largest public policy Ph.D. program, with a core curriculum including cost benefit and cost effectiveness analysis, decision analysis, empirical analysis, micro-economics, O.R., policy analysis, and social and behavioral science. On average, there are 110 Ph.D. candidates per class, including two or three recent Air Force Academy graduates.

Since the early 1950s, the Air Force has sent a select group of officers to RAND each year as part of the Air Force Fellows Program. These officers participate in RAND research projects and serve as ongoing liaisons between scientific research and military operations.

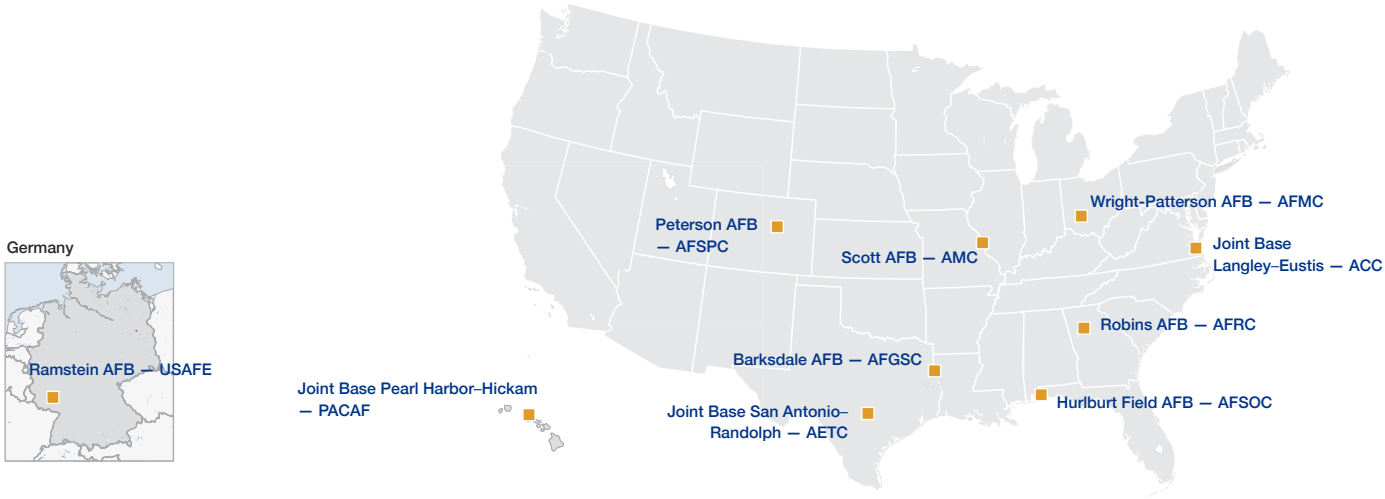
Air Force Organizational Alignment of Operations Research

The United States along with most NATO countries have adopted the continental staff system (also known as the general staff system) in structuring their militaries' staff functions. Each staff position in a headquarters or unit is assigned a letter-prefix corresponding to the formation's element and one or more numbers specifying a role. The Air Force and the United States Strategic Command use the number "9" to designate the function of O.R. For example, on the Air Staff, the Studies, Analyses, and Assessments directorate is the Air Force A9. In contrast, all the other military services, combat commands, and the joint staff organize their O.R. function under the number "8," meaning within their resource directorate. The Air Force A9 director is a civilian in the Senior Executive Service (SES) with the rank equivalent to a three-star general, and the Strategic Command J9 is led by a civilian executive with the rank equivalent to a one-star general. Both directly report to the commander of their respective organizations.

In the past decade, the U.S. Air Force has organized to ensure the integration of O.R. throughout the enterprise. The Air Force consists of ten major commands (MAJCOMs) that have either functional or regional responsibilities. These MAJCOMs have a headquarters staff and supporting Numbered Air Force. The Numbered Air Forces have two chains of command: one through the MAJCOM for organize, train, and equip functions and the other to a combatant commander for warfighting. In 2004, the commander of the Sixteenth Air Force, headquartered at Ramstein Air Force Base, Germany, created on his staff an Analyses, Assessments, and Lessons Learned (designated as the "A9") Directorate as his independent, direct-reporting, O.R. staff. The successes of that analytic team initiated a significant change in how the Air Force organized O.R. In 2006, the Secretary of the Air Force directed the Headquarters Air Force, all MAJCOMs, and all Numbered Air Forces to establish an Analyses, Assessments, and Lessons Learned Directorate.

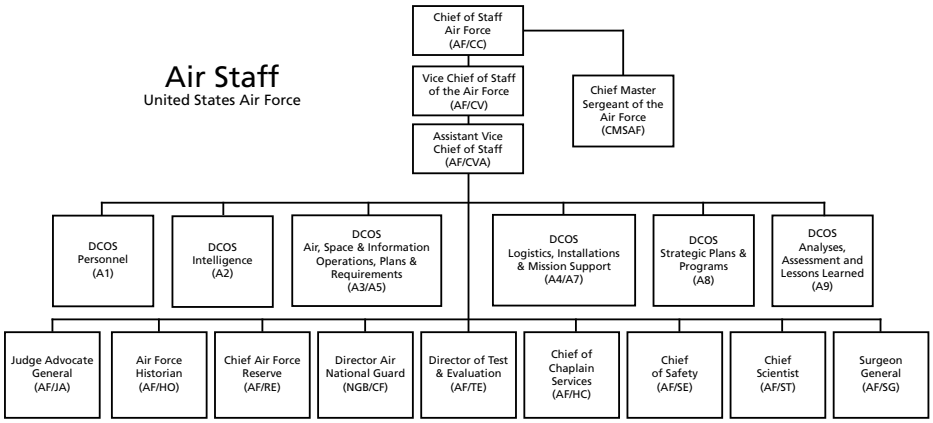
In Air Force colloquial, the "A9s" directly support each of their commanders with O.R. Today, 492 active duty military and 849 civilian O.R. analysts are providing high-caliber, decision-quality analyses supporting critical fiscal and military choices across the full spectrum of Air Force operations. The current organization structure with each MAJCOM and Numbered Air Force having an analysis cell reporting directly to the commander is the same alignment that was originally established in the Army Air Forces in 1942.

Air Force MAJCOMs ■ MAJCOM Headquarters



Major Analytic Centers and Their Missions

At Headquarters Air Force (often called the Air Staff), the Studies, Analyses, and Assessments Directorate (AF/A9) at the Pentagon in Washington, D.C., consists of more than 150 military and civilian employees providing analyses and assessments in support of the Secretary of the Air Force and Chief of Staff of the Air Force. As the leader of the Air Force Analytic Community, the director of AF/A9 provides AF-wide policy and guidance, and initiates actions to ensure that comprehensive, defendable studies and analyses underpin warfighting and force capability assessments. The director of AF/A9 also analytically fireproofs the Secretary and the Chief of Staff of the Air Force decisions and informs Air Force leadership responses to emerging issues and external studies.



AF/A9 is comprised of four directorates: the Office of the Chief Analyst (A9A), Resource Analysis Directorate (A9R), Force Structure Analysis Directorate (A9F), and Warfighting Integration Analysis Directorate (A9I). The Chief Analyst and his team in A9A conduct quick-turn assessments (usually less than 30 days; often one week or less) and provide force development support to the entirety of the Air Force's analytic career field, both military and AF civilian employees. The Resource Directorate conducts analyses supporting resource allocation and budget decisions involving personnel, infrastructure, and equipment. The Force Structure Directorate conducts analyses using a hierarchy of models ranging from specific combat engagement to entire air campaigns and war scenarios. Their analyses provide optimal aircraft, satellite, and missile recommendations to senior Air Force leaders. The Integration Directorate conducts analyses of cross-cutting capabilities, such as space, intelligence, and cyber. It also evaluates Air Force systems in conjunction with the other military services to assess their synergistic effectiveness. A9I also maintains the Air Force's Studies Repository, and it provides the government oversight of RAND Project AIR FORCE.

MAJCOM analytic directorates, called the A9s, are composed of military personnel, government civilian employees, and contractor personnel. Congress, through Title 10, designates the Air Force responsibilities for organizing, training, and equipping the force. The A9s conduct analyses and assessments in support of their respective MAJCOMs. A brief description of their function within the ten major commands follows:

MAJCOM: A9 ANALYTIC DIRECTORATES

ORGANIZING—TRAINING—EQUIPPING

ACC	Air Combat Command	At Joint Base Langley-Eustis in Hampton, Virginia, it controls all the Air Force fighter and intelligence aircraft and systems. The analysts assigned to Headquarters ACC/A9 provide analyses and lessons learned support to ACC units and staff. These analysts provide insights for current and future forces and their operations to improve warfighting effectiveness and efficiencies.

MAJCOM: A9 ANALYTIC DIRECTORATES

AETC	Air Education and Training Command	At Joint Base San Antonio–Randolph, Texas, it organizes all the Air Force recruitment, initial and follow-on training, and career education. AETC is unique, in that rather than an A9, it has a Studies and Analyses Squadron. The commander is a critical position in which career analysts demonstrate leadership and their potential to be promoted to colonel. Their mission is to enhance training and education by conducting studies, performing operational tests, evaluating new ideas and technologies, and developing along with assessing training programs. They focus on pilot proficiency, training requirements systems analysis, training capabilities, and resource analysis, providing analytical advice, developing technology solutions, and conducting testing and evaluation.
AMC	Air Mobility Command	At Scott Air Force Base near Belleville, Illinois, it operates all the airlift and aerial refueling aircraft along with Presidential support aircraft. AMC's A9 provides analyses and operational assessments to support senior-level Air Force and combatant commander decisions regarding the movement of forces into and within combat theaters, including surge responses involving all other Services (Army, Navy, Marine Corps) and coalition partners. These analysts perform studies of airlift, air refueling, and aeromedical evacuation for current contingencies and possible future wars. They assess future aircraft alternatives for cargo and passenger transportation. In addition, they conduct capabilities and requirements analysis, optimize personnel and infrastructure, and assess impact of decision alternatives on the Global Transportation Network.
AFMC	Air Force Materiel Command	At Wright-Patterson Air Force Base in Dayton, Ohio, it conducts new aircraft and system research and development and all Air Force logistics. This command has also recently been given the responsibility for planning and budgeting for all Air Force base-level support functions, such as security forces, civil engineering, and airfield operations. AFMC is responsible for over half of the Air Force budget. Prior to major system acquisitions, it conducts development planning to investigate new technologies and approaches. This phase culminates in an extensive analysis of alternatives that evaluates the best approach to meet future requirements. The analysts then support source selection evaluations of alternative contractor proposals for the system acquisition. For systems in the Air Force inventory, AFMC is responsible for all the logistics. It is responsible for supply chain modeling and optimizing a $42 billion dollar inventory of spare parts. For all the aircraft, it analyzes weapon system availability modeling, including reliability, maintainability, and repair. AFMC evaluates and schedules aircraft fleet depot modifications and refurbishments.

MAJCOM: A9 ANALYTIC DIRECTORATES

	**AFRL**	Air Force Research Laboratory	Aligned under AFMC, AFRL has more than 1,000 scientists and engineers investigating and developing technologies to ensure the United States continues to be the premier air force in the world.
	**AFSPC**	Air Force Space Command	At Peterson Air Force Base in Colorado Springs, Colorado, AFSPC operates all Air Force satellites, including the global positioning system. It uses astrodynamics to examine satellite orbit periods and earth coverage. Its analysts support decisions on satellite acquisitions. Additionally, AFSPC examines satellite reliabilities and replacement launch schedules. It also evaluates space debris and avoidance along with the effect of maneuvering on satellite life. AFSPC analysts participate in studies within the national space community. AFSPC is also responsible for all Air Force cyber operations and has analysts examining defensive and offensive uses of information technologies.
	**AFSOC**	Air Force Special Operations Command	At Hurlburt Field, in Okaloosa County, Florida, AFSOC organizes for and conducts the air portion of unconventional operations. Special operations are usually conducted by a few highly trained and uniquely equipped combatants in a low-profile manner that aims to achieve the advantages of speed, surprise, and violence of action against an unsuspecting target. AFSOC/A9 analyzes major acquisition programs, manned and unmanned aircraft modifications, and advanced science and technology initiatives relating to special operations.
	**AFGSC**	Air Force Global Strike Command	At Barksdale Air Force Base in northwest Louisiana, it leads the nuclear weapon delivery vehicles including bombers and intercontinental ballistic missiles and all strategic command and control architecture and network assets. AFGSC analysts conduct command-wide and functional assessments of current and future nuclear plans, operations, logistics, and sustainment requirements. They explore resource decisions and budget trade-offs for current nuclear war plans and future nuclear scenarios. These analysts are experts in effects of nuclear detonations and ensure the United States maintains the continued deterrence against nuclear attack, which was crucial in winning the Cold War.
	**AFRC**	Air Force Reserve Command	At Robins Air Force Base in Houston County, Georgia, it provides a ready surge capacity in the event of major combat contingency and augments current operations through part-time military members and units. AFRC's A9 conducts analysis on the development and maintenance of this critical component of the Air Force. Analysts perform studies and analyses that underpin the reserve's strategic planning, operational requirements, modernization and recapitalization of systems and programs, and the AFRC's planning, programming, budgeting, and execution processes.

In addition to the "organize, train, and equip" MAJCOMs described earlier, two Air Force MAJCOMs have regional responsibilities:

MAJCOM: A9 ANALYTIC DIRECTORATES

REGIONAL MAJCOMs

USAFE	U.S. Air Forces Europe	U.S. Air Forces Europe at Ramstein Air Base in Germany and Pacific Air Forces at Joint Base Pearl Harbor-Hickam on the island of Oahu, Hawaii. Their A9s provide analyses supporting theater security cooperation efforts as well as emerging contingencies, including humanitarian relief efforts. Analysts in these organizations are an integral part of the planning and execution of war games, theater exercises, and "real-world" operations unfolding in their respective regions. They provide analyses in developing and executing deliberate, contingency, crisis, and adaptive planning. The Numbered Air Forces aligned under these commands conduct command and control through their Air Operations Center. The assigned analysts augmented with deployed analysts from other commands provide critical assessments within the Air Operations Center.
PACAF	Pacific Air Forces at Joint Base Pearl Harbor–Hickam	

The Air Force has many organic analytic teams supporting various organizations and their missions. The following paragraphs highlight the function of these teams:

AIR FORCE ANALYTIC TEAMS

ANALYTIC SUPPORT

AFPC	Air Force Personnel Center	At Joint Base San Antonio–Randolph, Texas, it manages recruitment, development, promotions, and retirements of all Air Force regular military members and civilians. The analysis branch at AFPC conducts studies and analyses that span the personnel life cycle, including accessions, compensation, benefits, separations, and retirements. They provide analytical products, reports, and briefings, including specialty health assessments, year group analyses, skill-pairing vector targets, and officer promotion trends. They develop optimization models, such as Professional Military Education classification, general officer skill pairing, and initial officer specialty determination. They forecast specialty inventories, set accession targets, and determine force-shaping policies.
OAS	Office of Aerospace Studies	Located at Kirtland Air Force Base in Albuquerque, New Mexico, it conducts analyses supporting acquisition program planning. One of the key lines of effort is the conduct of analyses of alternatives (AoAs), which the Air Force relies on to provide an analytical comparison of the operational effectiveness, cost, and risks of technical materiel to meet operational requirements. AoAs document the rationale for identifying and recommending a preferred solution or solutions to mission shortfalls. OAS analysts often collaborate with their fellow O.R. analysts at the MAJCOMs.

AIR FORCE ANALYTIC TEAMS

	**AFOTEC**	Air Force Operational Test and Evaluation Center	Headquartered at Kirtland Air Force Base in Albuquerque, New Mexico, its specialized analysts provide technical capabilities and information needed to scope, plan, execute, and report independent tests and evaluations of new aircraft and major systems. They provide critical review of test concepts, analytical approaches, and test program documents as well as lead test design, modeling and simulation, data collection, and analysis.
		**53rd Test Management Group**	Located at Eglin Air Force Base in Walton Beach, Florida, it is the Combat Air Forces' lead for planning, executing, analyzing, and reporting on more than 200 Air Combat Command operational tests annually. The group strives to improve warfighters' combat capability by fielding effective and suitable systems and capabilities. It develops new tactics and employment concepts for fighters, bombers, unmanned aerial vehicles, electronic warfare, weapons, sensors, chemical defense, agile combat support, mission planning, and aircrew training systems. In addition, it directs tests for solutions to urgent combat requirements.
	**AFCAA**	Air Force Cost Analysis Agency	AFCAA performs independent component cost analyses for major space, aircraft, and information system programs as required by public law and Department of Defense policy. It is responsible for cost estimating and for enhancing the state-of-the-art in cost analysis. The AFCAA director provides guidance, analytical support, and quantitative risk analyses to 11 MAJCOMs and the Air Force corporate staff on development of cost per flying-hour factors and resource requirements. AFCAA performs special studies supporting long-range planning, force structure, AoAs, and life-cycle cost analyses.

PROJECT AIR FORCE

In addition to its organic analytic capability, the Air Force continues a partnership with the RAND Corporation. Army Air Forces General "Hap" Arnold partnered with several leaders from industry and academia to found Project RAND in 1945. Project RAND published its first report, *Preliminary Design of an Experimental World-Circling Spaceship*, in May 1946. Today, RAND Project AIR FORCE is the original of the now four federally funded research and development centers within RAND. RAND Project AIR FORCE continues the mission to conduct an integrated program of objective analysis on issues of enduring concern to Air Force leaders. This mission includes conducting research on such topics as ways the Air Force can attract future leaders, how it can best acquire new equipment, and how it can best organize its active and reserve units. The Air Force's need for analytic support has led to the establishment of four research programs within RAND Project AIR FORCE:

RESEARCH PROGRAMS

- **The Strategy and Doctrine Program**
  The Strategy and Doctrine Program seeks to increase knowledge and understanding of geopolitical and other problems in the national security environment that affect Air Force operations. The program maintains expertise in defense strategy; regional analysis; the objectives and tasks of evolving joint operations; and the potential contributions of air and space power to joint operations, defense planning, and requirements for force development.

- **The Force Modernization and Employment Program**
  The Force Modernization and Employment Program identifies and assesses ways in which technological advances and new operational concepts can improve the Air Force's ability to satisfy a range of future operational demands. This research involves assessments of technology feasibility, performance, cost, and risk. The program assesses major air, space, and cyber force components needed in the future and the systems and infrastructure supporting their operations. Areas of specialization include intelligence, surveillance, reconnaissance, mobility, long-range strike, combat air forces, command and control, space, cyber, and nuclear.

- **The Manpower, Personnel, and Training Program**
  The Manpower, Personnel and Training Program concentrates on questions about workforce size and composition and the best ways to recruit, train, pay, promote, and retain personnel. The program's research encompasses the total workforce: active duty, guard, reserve, civilian, and contractor personnel.

- **The Resource Management Program**
  The Resource Management Program analyzes policies and practices in the areas of logistics and readiness; outsourcing, privatization, and contracting; the industrial base; planning, programming, and budgeting; infrastructure; and weapon-system cost estimating. The goal of this program is to maximize the efficiency and effectiveness of Air Force operations in a resource-constrained environment.

Each RAND Project AIR FORCE study is approved by the Vice Chief of Staff of the Air Force and is sponsored by a general officer or a member of the Senior Executive Service. The results of RAND Project AIR FORCE research are communicated to the Air Force through informal discussions, briefings, publications, and the Internet. Project AIR FORCE

RAND PROJECT AIR FORCE

- RAND Project AIR FORCE research findings are given the widest possible dissemination consistent with their security classification to other individuals and groups, both inside and outside the government, who may benefit from them.
- RAND Project AIR FORCE's work for the Air Force spans manpower, modernization, acquisition, and strategy, and the analysis techniques it applies to these problems are equally diverse.

research findings are given the widest possible dissemination consistent with their security classification. This policy, encouraged by the Air Force, releases the work to the outside professional community for validation of its accuracy and competence and to other individuals and groups, both inside and outside the government, who may benefit from it. Over the years, RAND Project AIR FORCE has been the source of thousands of reports that have become part of the general scientific literature.

Today, RAND Project AIR FORCE performs both classified and unclassified research in programs treating defense, international, and domestic issues. The current staff numbers nearly 850 researchers, with about 20 percent being operations researchers, mathematicians, physical scientists, engineers, and statisticians and another 26 percent holding quantitatively focused policy analysis and economics degrees. RAND Project AIR FORCE remains a critical activity at RAND, accounting for roughly 20 percent of RAND's current research activities. RAND Project AIR FORCE continues to tackle the Air Force's most challenging and important problems.

Under Air Force guidance and sponsorship, RAND Project AIR FORCE played a central role in the formation and definition of the disciplines of O.R. and systems analysis. The breadth of the Air Force's mandate to RAND Project AIR FORCE with its involvement in almost every aspect of Air Force operations enabled RAND Project AIR FORCE researchers to build a foundation of specialized studies over many years that formed the basis for its broader policy analysis.

The latitude granted RAND in defining its research agenda led to foundational work that still forms the basis of O.R. today. The simplex method, game theory, Monte Carlo techniques, dynamic programming, conceptual approaches to defining and quantifying cost and risk—all were developed or first practically applied at RAND.

As the field of O.R. developed and matured, the emphasis of RAND's work with the Air Force shifted. The focus today is less on fundamental research on analytic methods than on sophisticated tailoring and application of analytical tools to address critical problems and support decisionmaking by Air Force leaders. RAND Project AIR FORCE's work for the Air Force spans manpower, modernization, acquisition, and strategy, and the analysis techniques it applies to these problems are equally diverse.

Still, a review of RAND Project AIR FORCE research papers from the past ten years—classified and unclassified—reveals that fully 35 percent of projects relied on classic O.R. tools and methods to reach their findings. Each RAND research project is a tailored analysis effort, and these projects typically must improve and advance their research methodologies to achieve their objectives. RAND documents and publishes its research and the methodologies that support them.

In addition, roughly 5 percent of Air Force research at RAND is explicitly aimed at improving and promulgating O.R. methods and tools. RAND researchers remain active members of the O.R. community, most notably through participation in the Military Operations Research Society.

Air Force Management of Modeling and Simulations (M&S) and Studies

Air Force Instruction 16-1005, *Modeling and Simulation Management*, establishes several organization constructs and procedures to guide development of modeling and simulations (M&S) and assist in applying O.R. throughout the enterprise.

For governing M&S policy and development, the Air Force has instituted an M&S Tri-Chair construct. The Air Force M&S Executive Steering Committee has three-star-equivalent principals from operations for the simulators, from acquisition for the system life-cycle management, and from studies and analysis for the decision support. Subordinate to the Executive Steering Committee is the Air Force M&S Steering Committee, which consists of two-star-equivalent leaders from the same function areas. Because of the extensive overlap between models supporting acquisition and decision support, the Air Force formed a combined Council of Colonels to identify and resolve M&S issues.

While the conduct of analyses is controlled by the individual analysis centers, coordination of analysis policy is orchestrated through Air Force Analysis Community (AFAC), which consists of all the military and civilian O.R. analysts along with other government employees conducting O.R. in the Air Force. The Director of Air Force Studies, Analyses, and Assessments (AF/A9) in the Pentagon chairs the AFAC Executive Committee (EXCOM), which is composed of all the general officer and Senior Executive Services (SES) members that supervise analysts. The AFAC EXCOM meets at least once annually. The Air Force Chief Analyst directs the subordinate AFAC Steering Group of all the colonels or Government Service Level 15 (GS-15) civilians, who are senior leaders in the analytic enterprise. The Steering Group meets a couple of times per year, including in conjunction with the annual Air Force Operations Research Symposium (AFORS). The AFAC Steering Group may also charter subordinate working groups to focus on specific areas. One long-standing group is the Operational Assessment Working Group, which defines an approach to identify and display measures of performance and effect, particularly for wartime operations.

One of the significant products of the AFAC is the Air Force Standard Analysis Toolkit (AFSAT), which is a registry of analytic computer models and tools. Air Force Instruction 16-1003 directs management of the AFSAT. The different AFSAT levels indicate the extent of verification and validation, model documentation, configuration control, and user community.

- Coordination of analysis policy from the individual analysis centers is orchestrated through the Air Force Analysis Community (AFAC). One of the significant products of AFAC is the **Air Force Standard Analysis Toolkit,** which is a registry of analytic computer models and tools.

Besides managing M&S applications, the Air Force conducts and oversees many studies and analyses. The Air Force formed the Study Governance Board in 2012 to manage these studies and to provide senior leader oversight and policy guidance. As a result, the Air Force implemented a Study Registry Program (SRP) through Air Force Instruction 90-1603, *Air Force Studies Management and Registration,* to ensure new efforts build on the results of past studies. The SRP does not warehouse the actual studies because the Defense Technical Information Center (DTIC) provides that library service for all of the Department of Defense. DTIC enables the Air Force to store electronic copies, including classified reports and those with limited distribution, as appropriate. RAND's studies are posted on its own website as well as listed in the SRP. Air Force Instruction 65-509, *Business Case Analyses,* describes how to conduct resource trade studies.

Summary

The Air Force, along with its partnership with RAND Project AIR FORCE, has effectively integrated O.R. throughout its structure. The Air Force maintains a career field of military analysts ranging from lieutenants to colonels. The Air Force also complements its teams with career government civilians, many of whom include former military members. The Air Force has educational institutions offering bachelor's, master's, and doctoral degrees in O.R., and the Pardee RAND Graduate School offers Ph.D.'s in policy analysis with a specialization in O.R. The Air Force has established O.R. analytic units that directly report to the commanders of the Air Staff and major commands, ensuring that high-quality, relevant analysis is readily available to support major decisions at the highest levels.

IMAGE CREDITS

Page 1: U.S. Air Force/Staff Sgt. Sean Martin
Pages 2–3: Bodine-Baron, Elizabeth, et al., Examining ISIS Support and Opposition Networks on Twitter, Santa Monica, Calif.: RAND Corporation, RR-1328-RC, 2016.
Page 4: U.S. Census Bureau; NIST Archives
Page 7: Reprint of the Princeton University Press, Princeton, New Jersey, 1957 edition; http://store.doverpublications.com/0486428095.html#sthash.JnYapof1.dpuf
Page 12: U.S. Air Force/Tech. Sgt. Ryan Crane
Page 13: U.S. Air Force/Senior Airman Brittany Y. Auld; U.S. Air Force/Airman Greg Nash
Page 14: U.S. Air Force/Airman 1st Class Cory W. Bush; U.S. Air Force/Samuel King Jr.
Page 15: U.S. Air Force/Airman 1st Class Benjamin Wiseman
Page 16: U.S. Air Force/Staff Sgt. Greg C. Biondo
Page 17: U.S. Navy/Mass Communication Specialist 2nd Class Brian T. Glunt; U.S. Air Force/Airman 1st Class Christian Clausen
Page 18: U.S. Air Force/Samuel King Jr.
Page 19: U.S. Air Force graphic/Staff Sgt. John Bainter; WikiCommons/Charles Joseph Minard
Page 20: U.S. Air Force/Staff Sgt. Armando A. Schwier-Morales; U.S. Air Force/Airman 1st Class Kevin Tanenbaum
Page 21: Missile Defense Agency (courtesy photo)
Page 22: U.S. Air Force/Airman 1st Class Emily A. Bradley
Page 23: DoD/Senior Airman Julianne Showalter, U.S. Air Force; U.S. Air Force/Staff Sgt. Alex Mercer
Page 24: U.S. Air Force (courtesy photo); U.S. Air Force/Bobbi Zapka
Page 25: DoD/Photographer's Mate 3rd Class Jarod Hodge
Page 26: Lockheed Martin
Page 27: iStock,Getty Images.monsitj; U.S. Air Force (courtesy photo)
Page 28: U.S. Air Force
Page 29: U.S. Air Force/Senior Airman Christopher Callaway
Page 30: Lutz Gretschel
Page 31: AFHRA; U.S. Air Force (patch); AFHRA; AFHRA (background)
Page 32: U.S. Army Air Forces; AFHRA; U.S. Army Center of Military History
Page 33: U.S. Army Air Forces
Pages 34–35: U.S. Army Center of Military History
Page 36: U.S. DoD Public Domain/U.S. Army Air Forces
Page 37: Unknown (Smithsonian Institution); U.S. Air Force
Page 38: Ford Motor Company Archives
Page 41: U.S. Air Force
Page 42: Department of the Army/Major General George S. Eckhardt; U.S. Air Force
Page 43: MORS; U.S. Air Force (AFSAA emblem)
Page 44: U.S. Air Force/Airman 1st Class Chris Massey; U.S. Air Force
Page 45: Peter Egeli, Flickr; U.S. Air Force
Page 46: U.S. Air Force; U.S. Air Force/Billy Smallwood
Page 47: U.S. Air Force/Joel Strayer; U.S. Air Force/Michelle Gigante
Page 48: USSTRATCOM; U.S. Air Force
Page 49: U.S. Air Force: U.S. Government
Page 50: Department of Defense/Senior Master Sgt. Andy Huneycutt, U.S. Air Force
Page 51: U.S. Air Force/Sue Sapp; U.S. Air Force/Senior Airman Brett Clashman; U.S. Air Force/Staff Sgt. Whitney Stanfield
Page 53: U.S. Air Force/Tech. Sgt. Jacob N. Bailey
Page 54: U.S. Air Force
Page 55: U.S. Air Force Public Affairs/Mike Kaplan; RAND/Diane Baldwin
Page 57: WikiCommons
Pages 57–61: U.S. Air Force (MAJCOM emblems)